PULLOUT! Messier Catalog of 109 Sky Treats

Astronomy®

March 2007

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Window into the violent universe

EXTREME STARS

Superdense neutron stars show astronomers exotic worlds of pressure, magnetism, and gravity

NEW COLUMNIST! Stephen James O'Meara p. 18

What makes stars explode? p. 38

See winter's best planetary nebulae p. 60

Mars updates p. 20 and p. 24

PLUS:

Secrets of the brightest galaxies p. 26

Touchdowns on other worlds illustrated p. 58

How to search for supernovae p. 70

A pair of orbiting neutron stars collides, possibly creating a gamma-ray burst. The merged object's final state may be a black hole. p. 32

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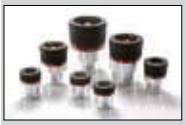

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DANA BERRY FOR *ASTRONOMY*

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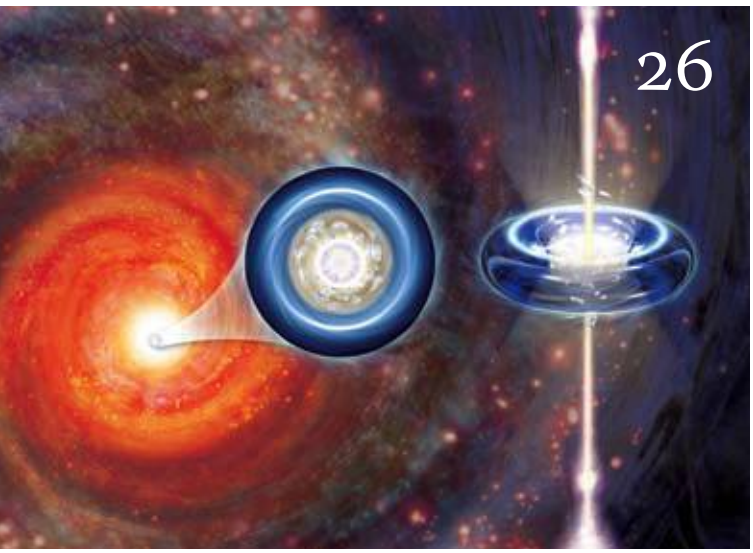

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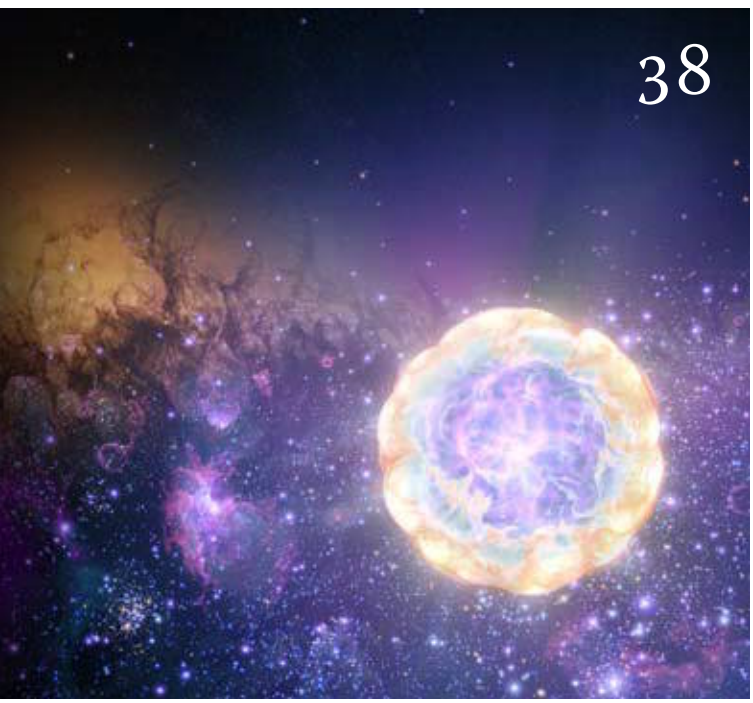

ADOLF SCHALLER FOR *ASTRONOMY*

Astronomy

VOL. 35, NO. 3

The world's best-selling astronomy magazine

march 2007

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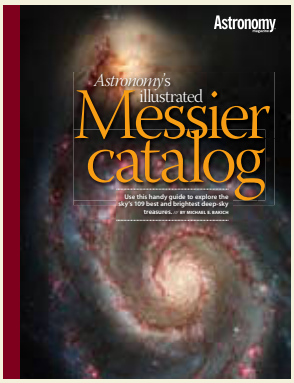
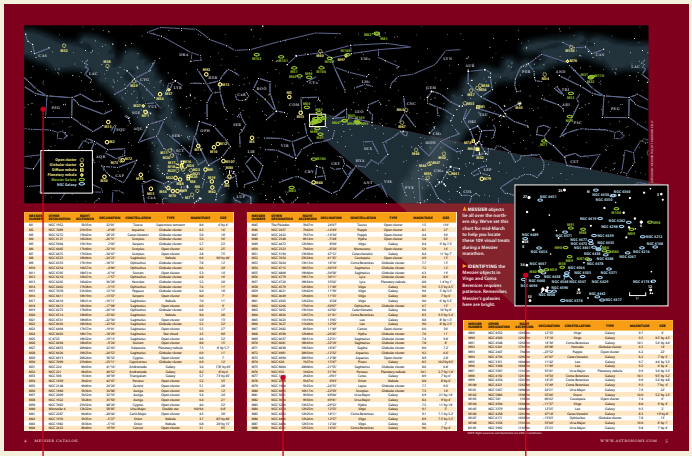
Explore the night sky's 109 best, brightest targets.





The all-sky map takes you from dusk to dawn

Get positions and data for all 109 objects

A close-up map zooms in on Virgo

PLUS: A beautiful image of each object in the Messier catalog! Everything you need to observe these deep-sky treats tonight!

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New faces at *Astronomy*

Please join me in welcoming two new members of the *Astronomy* magazine team: Stephen James O'Meara and Katie Neubauer.

Steve is undoubtedly well-known to many of you already: A celebrated observer, astronomer, and naturalist, he has long been recognized for his acute vision as an observer of deep-sky objects and solar system bodies.

In 1985, Steve became the first observer to visually recover Halley's Comet on its inbound swing toward the Sun. He also is known for sketching the "spokes" in Saturn's B ring prior to the Voyager 1 spacecraft's discovery of them. Steve has been a participant and lecturer at numerous amateur meetings and star parties.

Beginning this month, he will write a column for us titled "Stephen James O'Meara's secret sky." The monthly column will feature observational thoughts and tips from Steve that will undoubtedly add to your enjoyment of the heavens. His first column, on page 18, covers phenomena observed during last November's transit of Mercury. Steve's column adds value and enjoyment to what is already the world's best-selling astronomy magazine.

Steve has covered amateur astronomy for many years. He earned his bachelor's degree from Northwestern University and spent years as a staff member at *Sky & Telescope*, writing a monthly column for that magazine after he departed. Steve is the author or editor of several observing books, including *Deep-Sky Companions: The Messier Objects*; *Deep-Sky Companions: The Caldwell Objects*; and *Deep-Sky Wonders*. He also co-authored *Mars: The Lure of the Red Planet* with William Sheehan.

In addition, Steve and his wife Donna are expert volcanologists. The O'Mearas live in the right place for that field: Volcano, on Hawaii's Big Island. They have traveled around the world photographing volcano eruptions, and their work led to the book *Volcanoes: Passion and Fury*. Also, *National Geographic Explorer* broadcast a special on television focused on the couple's passion for volcanology.

Columnist Stephen James O'Meara (left) and Editorial Intern Katie Neubauer
ALOHA PHOTO ARTS STUDIOS AND *ASTRONOMY:* JIM FORBES

I'm sure you will greatly enjoy the addition of Steve's column in this and future issues of *Astronomy*.

Katie Neubauer joins our staff as an editorial intern. An English major and Professional Communication minor at Alverno College in Milwaukee, Katie will write news stories for Astronomy.com, edit articles, and contribute to the day-to-day workings of the magazine.

A Milwaukee native, Katie spends her free time reading poetry and novels, writing short stories, spending time with her family, and cooking. She lives on the city's east side with her cats Padre and Jasmine. After she graduates in May 2007, Katie will attend the University of Denver Publishing Institute to learn more about book publishing.

Welcome, Steve and Katie!

Yours truly,

David J. Eicher
Editor

Astronomy

Volume 35, Number 3

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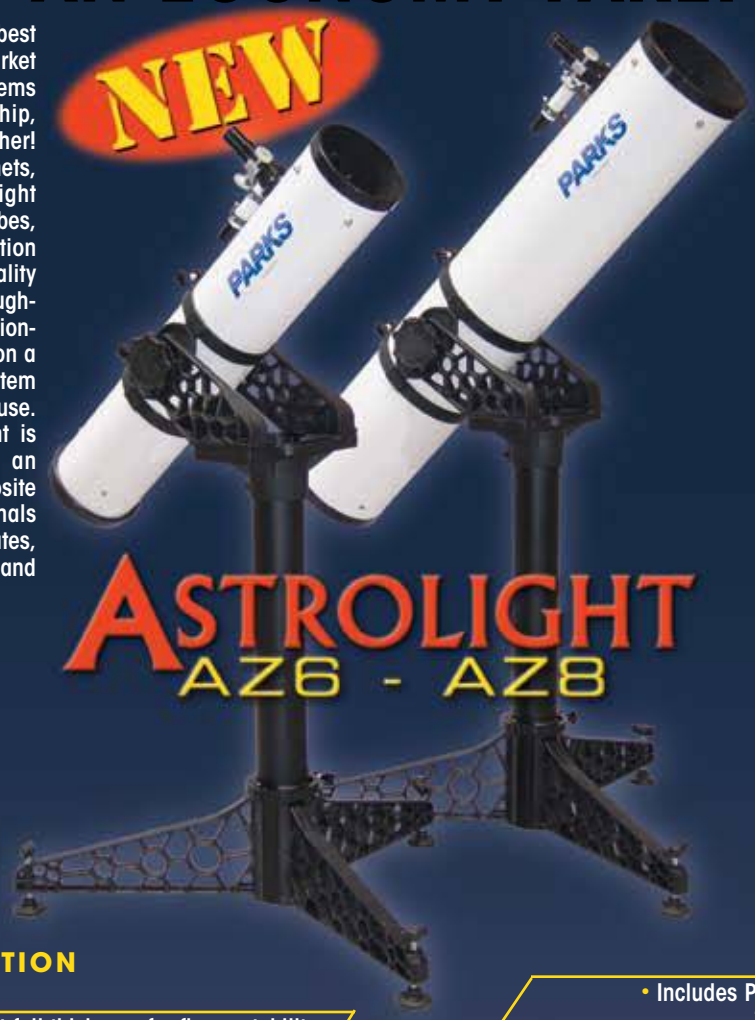

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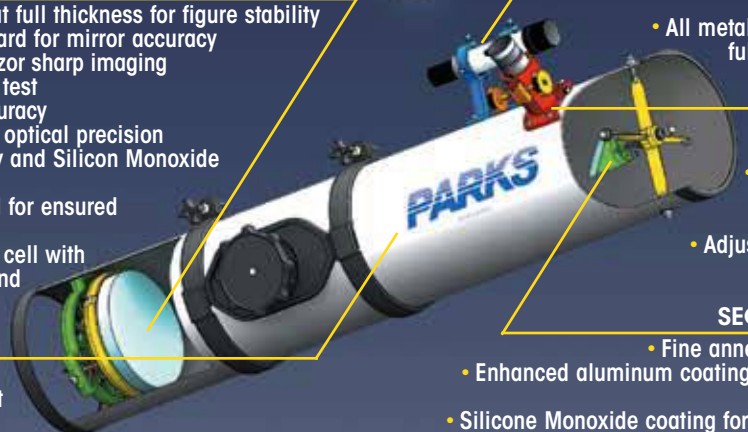

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Long live Hubble!

Irene Klotz reported on NASA's approval

of a Hubble repair mission by the space shuttle on Astronomy.com October 31, 2006 ("Hubble fix a 'go'"). This is some of the best news for science and astronomy I have heard in years — and there has been much good news! — **ROY GRANDY,** ERIN, ONTARIO

Deep-space hazards

I appreciated Bob Berman's "Space-travel woes" (October 2006). I am a retired engineer and spent my career designing nuclear power plants. My specialty was radiological analysis and radiation-shielding design.

Every time I read articles on the radiation-dose rates in deep space, and especially on Mars' surface, I wonder how we could possibly protect explorers.

Dose rates within a factor of 5 of what is normally experienced here on Earth (which also can vary by a factor of more than 10 from place to place) can be safe for long exposures. But the rates in space far exceed these values.

I have become pessimistic as to the success of long-duration human exploration for this reason and believe this problem must be faced head-on rather than considered a minor technical issue. Toward that end, bringing up the hazards inherent in deep-space exploration as you have done can only serve to raise this issue as necessary. **— HAROLD A. CAREWAY,** SAN JOSE, CALIFORNIA

Clairvoyant composer?

I was going over my MP3 files and noticed Gustav Holst's *The Planets* does not include Pluto. The piece must have been written before Pluto was discovered, but now Holst is, once again, correct. I noted, too, he did not include Earth — wonder what that means. **— FRANK CLARK,** EVERETT, WASHINGTON

Correction

The resolution of MRO's HiRISE camera was stated incorrectly in "Zeroing in on martian water" (December 2006). The resolution ranges from 10" to 13" (25 to 32 centimeters) per pixel. **— *ASTRONOMY* EDITORS**

We welcome your comments. Send letters to Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; e-mail to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

See it to believe it

I was puzzled by a comment in "Mercury crosses the Sun" (November 2006) about Mercury's November 8 transit.

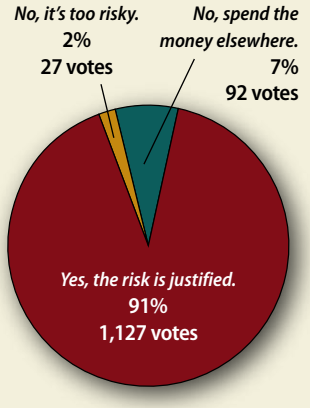
Michael Bakich wrote Mercury will subtend an angle of 10" and will be visible (although very small) in 7x35 binoculars. If you multiply 10" by 7, you get 70", which is way below naked-eye resolution (for most people, that's around 3'). So why would Mercury be visible in 7x35s? **— ANDREW PLANCK,** BOULDER, COLORADO

MERCURY'S TRANSIT
November 8 was visible through telescopes and binoculars. LESLIE MARCZI

Your math is sound, but the eye tells a different tale. Mercury is visible through small binoculars mainly because of contrast. It appears as a black disk against a brilliant background. The visibility of the Cassini Division in Saturn's rings is a similar phenomenon. At widest, the Cassini Division subtends much less than 1", but even observers using 2-inch telescopes easily pick it out. **— MICHAEL E. BAKICH, SENIOR EDITOR**

Online poll results

POLL QUESTION:
Did NASA make the right choice to send a fifth shuttle mission to fix Hubble?



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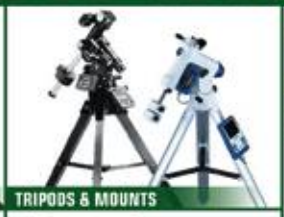
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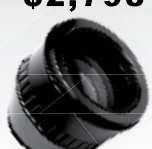

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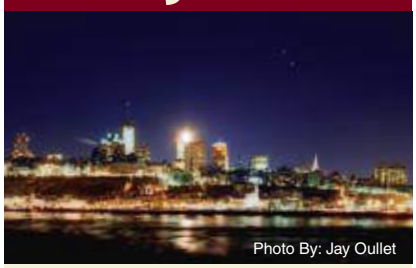
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BY BOB BERMAN

Enter the equinox

The vernal equinox. It's one of those rare events that reminds people Earth is a planet in space. The media gets on board, too: TV weathermen are sure to say "days and nights are equal today," even though it's never true. Astronomers know better, realizing that atmospheric refraction

bends the solar disk upward by its own diameter, letting us see the Sun even after it has set. This alters the day-night mix, boosting the actual annual sunshine by 1½ percent. It's demonstrated most clearly on the equinox, which has between 4 and 15 minutes more day than night. This solar excess is greatest farther from the equator, where Earth turns slower and where people spend more time in that "refracted Sun zone" alongside the terminator.

Days and nights are not even roughly equal at the poles. Researchers at the South Pole experience 24 hours of Sun on the equinox. No trace of night, no sign of equality. Just the Sun fully up, rolling leftward atop the horizon like a glowing bowling ball from a nuclear power plant. Long ago, experimenters grew sunflowers down there to see if they'd follow the Sun's horizontal motion, and they did. The poor plants slowly twirled around and around until they strangled themselves.

Everywhere else, the equinox Sun rises due east and sets precisely in the west. It's the best opportunity to find the cardinal compass points from your home, to orient yourself (originally, to know the direction east, toward the Orient).

Directions are a comfortable subject for backyard astronomers. We who live above the equator use the North Star as a sure-fire direction-finder, because Polaris hovers precisely due north with an accuracy of better than 1°. Advanced stargazers also know that Mintaka, the rightmost star of Orion's "belt," sets precisely due west, with an error of much less than 1°.

Campers and hikers instead use compasses, even though they're more than 10° wrong in much of the world. Compasses screw up in other ways, too. Because magnetic field lines run parallel to Earth's surface only in the tropics, in the Northern Hemisphere, a weight is added to the south pole of a compass needle in order to counteract magnetic dip — the north magnetic pole's downward pull on the north side of the compass needle. This asymmetry introduces errors caused by the greater inertia due to the added weight. For example, if you are traveling east and you change speed, the compass needle will move counterclockwise during deceleration and clockwise in acceleration. And in an airplane's banking turn, the compass weight moves down to the lower side of the plane, also causing an erroneous reading.

> THE STARS NEVER LIE, and neither does the equinoctial Sun.

The stars never lie, and neither does the equinoctial Sun.

Less well known, the vernal equinox is the only day the Sun's path is laser-straight across the sky. From April through August, a time-exposure photo reveals a highly curved solar arc that is concave toward the north. During the December half of the year, the Sun's path curves the opposite way, mimicking a giant rainbow in the south. But now, on the equinox alone, the Sun moves straight across the sky.

For Americans, 2007 brings the first-ever vernal equinox in daylight-saving time. So the Sun's highest elevation will occur around 1 P.M., not noon. At that moment, you'll observe the Sun's average yearly midday height for your location. It will climb 47 Sun-widths higher by late June, the same elevation it's gained since the winter solstice.

This also will be our final March 21 equinox, reckoned by Universal Time (Greenwich Mean Time). Starting next year, spring will begin on the 19th or 20th for the rest of our lives. It's all part of the 400-year calendar plan, in which a single century must endure unusually early equinoxes.

There's more. The period surrounding the equinox brings the year's most rapid increase of daylight. Daylight expands by 3 minutes daily in New York, 6 in Fairbanks. Twilight lengthens at its maximal rate, too.

This exploding sunlight brings countless consequences. For example, AM radio stations are heard for much greater distances at night, so, to limit interference, the FCC restricts many stations to daylight broadcasting only. Now, in March, the permitted period suddenly expands into the profitable prime-time evening hours.

So, the vernal equinox is much more than the start of spring. Ancient civilizations constructed Stonehenge-type pillars or passageways not simply because they had nothing better to do. They knew that this is when the planet seems to pause for an ephemeral moment, balanced and motionless, before rushing headlong into the year's solar extremes.

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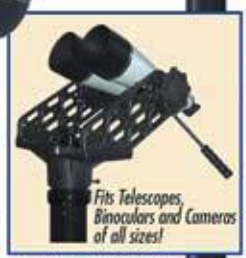

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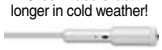
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BY GLENN CHAPLE

Ease into the Messier marathon

Last month, I admitted to being one of those individuals the general public might call a "no-lifer." Does the fact that I prefer spending hours under a starlit sky to watching "must-see" TV mean I have no life? I wonder.

Let me take you back to March 13, 1989. According to my calendar, the Moon was supposed to be close to Jupiter that evening. I decided to share that knowledge with my 8th-grade science students. "Go outside after dark tonight and look for the Moon," I told my class. Near the Moon, you'll see a bright star. That "star" is the planet Jupiter!"

There was no spontaneous applause. No collective gasp of awe. "Big deal!" snorted a boy sitting in the back of the room. I felt my face flush, but ignored his comment. It was typical of anyone who regards backyard astronomy as a "no-life" activity.

That night, I noticed a reddish glow in the northern sky — an aurora! For the next hour, I stared in awe at the most magnificent auroral display I had ever seen.

Reports of this aurora filled the morning news broadcasts. When I arrived at school, students rushed me, asking if I viewed the aurora. "Mr. Big Deal" joined our conversation and sheepishly asked, "Will we be able to see the northern lights tonight?"

"Possibly," I replied. "But nature doesn't always give you a second chance." And it didn't. There was no aurora that night, and I haven't seen one as glorious since.

So I again ask, "Do amateur astronomers lack lives?" We spend hours alone under the sky viewing amazing things: Jupiter's moons dancing or the Moon occulting a star. We experience cosmic events that the rank and file of society cannot even imagine. Whenever I hear people discussing the latest reality TV show after I've spent an evening under the stars, I question who really needs to get a life.

BEGIN WITH THE PLEIADES (M45) for your Messier 5K. See how many of the open cluster's bright stars you can spy with your naked eyes. Most observers can count four, five, or six stars arranged in the shape of a dipper, but slightly darker skies may reveal a seventh star. JOHN JOHNSON

The sky's mini-marathon

For the recreational runner, the ultimate challenge is the marathon. The backyard astronomer has a similar lofty goal: the Messier marathon. In this "race," participants try to view as many of Messier's 109 deep-sky objects as possible in a single night. A marathon — on the ground or in the sky — isn't something the novice should attempt. In the running world, there is a race that's appropriate for the beginner: the 5K. If you're an astronomical newbie (or a veteran skygazer unwilling to commit to an all-nighter), I offer you a "Messier 5K."

The targets in our Messier 5K are conveniently placed in the early evening sky. Their locations are plotted on the all-sky map you'll find in the middle of this issue. Most of them can be viewed in binoculars, especially from a dark-sky site.

The starting line for the Messier 5K course is the **Pleiades (M45)**. Once you've spotted this open cluster, off you go! From M45, you'll run through **M35**, **M37**, **M36**, and **M38**. These open clusters are aligned in a row that winds from Gemini's foot through Auriga's heart. Each appears as a hazy puffball in binoculars and a sprinkle of starlight in small scopes.

The best road races offer a scenic course, and our Messier 5K is no exception. When you arrive at the **Orion Nebula (M42)**, take a breather to admire one of the heavens' most splendid wonders. Once you're ready to return to action, move southeastward to pick up the star clusters **M41** and **M47**. Higher up and visible as a patch of light midway between the twin stars Pollux and Castor and the "sickle" of Leo is the Beehive Cluster **(M44)**.

Next, standing at the finish line are the galaxies **M81** and **M82**, both located a staggering 11 million light-years away! You can resolve both in the same eyepiece field of your scope, if you use a low magnification.

The weekend of March 17–18 offers the best conditions for a Messier 5K, thanks to a New Moon on the 19th.

Questions, comments, or suggestions? E-mail me at gchaple@hotmail.com.

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BY PHIL HARRINGTON

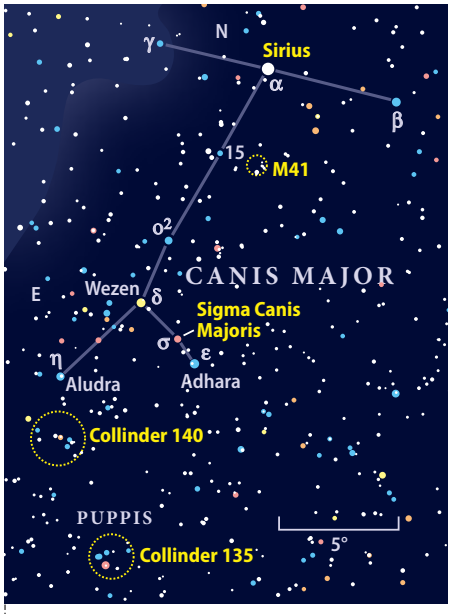
The sky's "Best in show"

As the owner of five dogs, I always look forward to the Westminster Dog Show held every February in New York City. Westminster attracts thousands of the finest canines from around the globe to vie for the coveted title "Best in show." The sky also puts on its own dog show every winter. We have Canes Venatici, the Hunting Dogs, rising in the northeast; Canis Minor, the Small Dog, high in the south; and Canis Major, the Large Dog, in the south-southwest.

Canis Major, home to the night's brightest star, **Sirius**, easily wins our celestial "Best in show." Prepare to be astounded when you first spot Sirius through your binoculars. No, you won't see its famous white-dwarf companion, but it's still quite a dazzler! Sirius, a white, type-A star, lies only 8.6 light-years away.

Shift Sirius toward the top (north) of the field, and then take a look near the bottom (south) for a clump of faint stars. That's the open cluster **M41**. For astro-history buffs, Greek scientist Aristotle (384 B.C.–322 B.C.) discovered M41 in 325 B.C. Today's 50mm binoculars reveal about 20 faint stars sparkling like fragments of diamond dust. Using 70mm or larger binoculars, you may notice one of the group's center stars glows with a subtle reddish tint, while the others show hints of yellow and orange.

Scan southward along the dog's imaginary body to the triangle formed by Wezen, Adhara, and Aludra. Wezen marks the tail's base, Adhara a hind leg, and Aludra the tail's tip. Although the area is littered with stars, a singularly spectacular reddish star floats near Adhara. Tomm Lorenzin, author of a 2,000+ online observing guide (www.1000plus.com/2000plus), describes it as "a bright, ripe kumquat." Tomm's kumquat, known officially as **Sigma (σ) Canis Majoris**, contrasts beautifully with the surrounding white and blue-white stars.



CANIS MAJOR secures its spot as big dog with its offer of multiple open clusters for binocular observers. *ASTRONOMY:* ROEN KELLY

Search half a binocular field south of Aludra for a right triangle of three bright stars accompanied by many fainter points. This little-known star cluster is an easy target through just about any binoculars. Its large size and sparseness, however, masked its true nature until Swedish astronomer Per Collinder included it as number 140 in his catalog of widespread star clusters. The 30 stars in **Collinder 140** range in brightness from 5th magnitude to fainter than 9th and form a triangle.

Finally, drop another binocular field to the southwest, just across the border into Puppis, to find the open cluster **Collinder 135**. Its brightest member, 3rd-magnitude Pi (π) Puppis, is classified as an orange supergiant and also stands out nicely among the other blue-white cluster stars. Collinder 135 also includes the double star Nu^1 (ν^1) and Nu^2 (ν^2) Puppis, just north of Pi, and a solitary 5th-magnitude star to the west. Together, they give the cluster a distinctive arrowhead shape.

In a sense, Aristotle's M41 sighting might be called the first Messier marathon. Of course, today the Messier marathon is a bit more involved, as my friend Glenn Chaple menioned in his column this month (page 14). Every year around the vernal equinox, amateurs around the world try their luck at spotting as many of the 109 Messier objects as possible in one night. It's a fun way to herald the arrival of spring.

Each year, Glenn challenges me to run the marathon against him. Each year, I accept. And each year, recently, cloudy skies have done us in. If it's clear and we pull this off, we'll report on our results in the August issue. If you try the full marathon or Glenn's 5K, be sure to let us know how you do. E-mail me at phil@philharrington.net.

Next month, we'll visit mighty Leo the Lion. Unil then, remember, two eyes are better than one!

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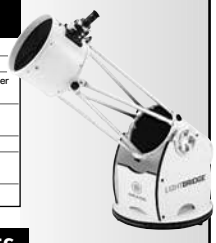

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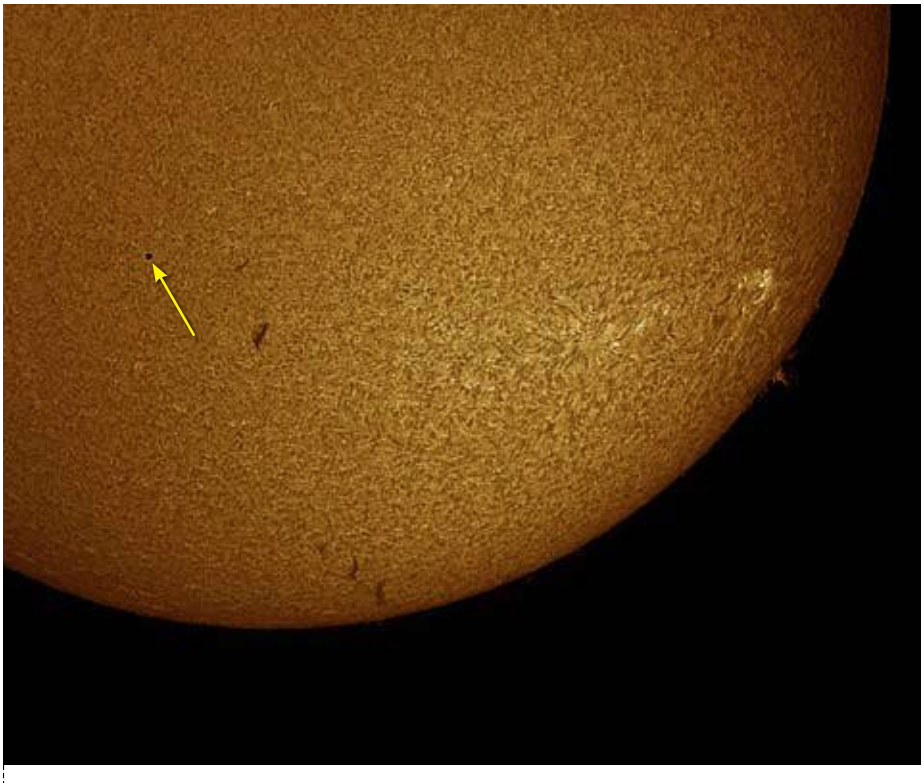
BY STEPHEN JAMES O'MEARA

Solar mindfreak

Have you ever watched *Mindfreak* on A&E Network? The series, hosted by illusionist Criss Angel, is my inspiration for this month's column. Instead of the escapist or levitation feats Angel performs, we'll review cases of solar system illusions. ☾ Watching Mercury pass in front of the Sun November 8, 2006, was magical. The planet's sharp limb vanished, its silhouette splintered into colors, its disk became oddly misshaped, and mysterious aureoles (some bright, some dark) magically materialized; after all, what is magic but the art of baffling an audience with illusions?

Mercury transits have long been steeped in witchery. In her 2005 book *The Planets*, Dava Sobel notes that after French astronomer and philosopher Pierre Gassendi became the first person to see one, on November 7, 1631, he wrote, "That sly [Mercury] … introduced a fog to cover the earth and then appeared sooner and smaller than expected so that he could pass by either undetected or unrecognized."

Gassendi also first mistook Mercury for a sunspot. And it's easy to understand why. The Sun's disk is about 200 times larger than the innermost planet's silhouette. Mercury can easily be mistaken for a sunspot. The planet appears smaller than expected because of irradiation — an optical phenomenon that causes a dark line or spot to shrink in size when it is seen against a bright background. (That's why you should wear black if you want to look slim.) Conversely, a bright object will appear to grow in size when it is seen against a dark background. Irradiation explains why the Moon's bright crescent appears larger in radius than the darker outline of its Earth-lit section.



MERCURY CROSSING the Sun (arrow) provided a number of illusions for solar observers with aided eyes November 8, 2006. PHIL JONES

Irradiation's causes have been ascribed to many factors: eye movement, spherical aberration in the eye-lens, the diffraction of light at the pupil, the way light stimulates the retina, the spreading of photons by rapidly moving air cells, and other optical conditions. Not surprisingly then, irradiation also contributes to another transit illusion: the infamous "black-drop" effect.

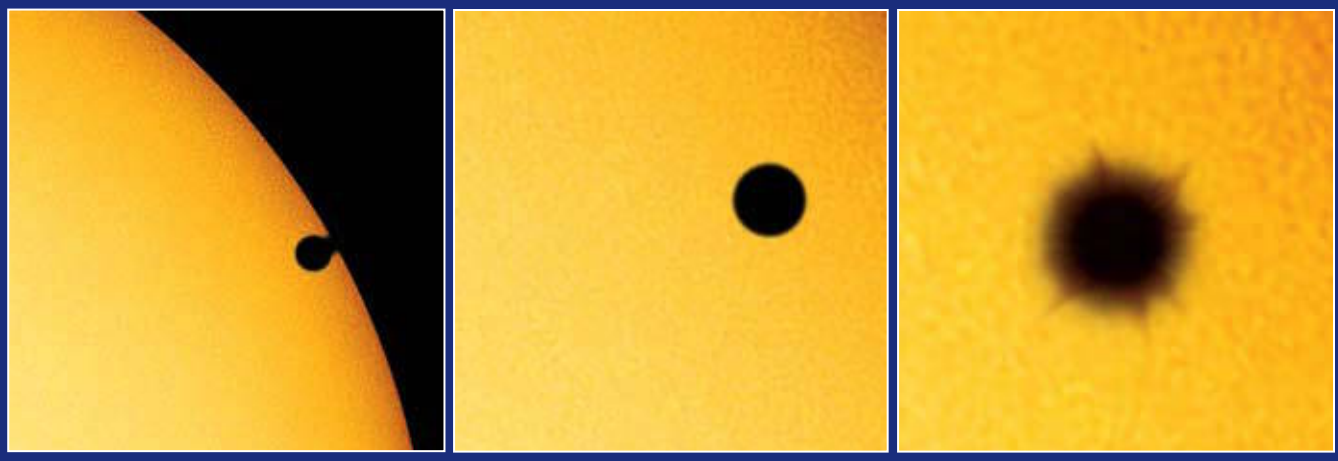
The effect is first seen at second contact, when Mercury's trailing limb starts to separate from the Sun's interior limb. Under certain conditions, the planet's silhouette will begin to stretch, as if it were stuck to the Sun's limb like a wad of gum to a shoe. As Mercury pulls away, the stretched silhouette thins until it pinches off from the Sun's limb. The reverse can happen when the planet begins to exit the solar disk. (You can simulate the black drop by choosing a bright background, closing one eye, and slowly bringing together the tips of your thumb and middle finger a few inches from your open eye.)

Scientists have proposed various theories to explain the effect. Beyond irradiation, explanations include the smearing effects of atmospheric seeing, diffraction within a telescope, eyesight, poor optics, a scope's resolving power, and magnification.

The magic show

When I watched November's Mercury transit from my home, I used a 4-inch refractor (stopped down to 1 inch), 105x, and a

The Mercury transit's sleight of hand



TURBULENCE IN EARTH'S ATMOSPHERE caused observers to see a slice of Mercury within the solar limb.

AFTER FOCUSING ON MERCURY for 10 seconds, do you view an afterimage in the bright area to the left?

MERCURY'S DISK appears smeared after it moves away from the limb, when it's fully immersed in the Sun's disk. *ASTRONOMY*: ROEN KELLY

Mylar solar filter. At the moment of second contact, a mysterious appendage formed on the planet's trailing limb as it entered the Sun's disk. The planet's circular silhouette morphed into a shadow shaped like a gourd. At times, the appendage appeared as a curious black bump flanked by an odd plume of light, both of which extended beyond the Sun's limb. The planet's leading limb was also fringed with light.

STEPHEN JAMES O'MEARA images the transit of Mercury through his 4-inch refractor. CHARLENE MEYERS

At least three optical illusions other than irradiation helped cause these effects.

First, turbulence in our atmosphere, on occasion, caused the Sun's limb to pulse and split in two. When it did, the outer limb included a slice of Mercury's silhouette, which appended itself to the planet's true disk, as shown in the first illustration above.

Second, because Mercury has no significant atmosphere, the bright arc of light preceding Mercury's leading limb must have been an illusion. Indeed, if you stare at an object against a bright background long enough, a portion of the eye's retina becomes fatigued. Focus your attention on the black circle in the second illustration above for about 10 seconds, then look at the bright surface next to it. You should see a negative (or bright) afterimage of the black circle. If you look at the black disk again, small, natural eye movements will carry the bright afterimage beyond the borders of the black circle, creating the illusion of an aureole. These same eye movements shifted Mercury's afterimage off the disk to create the third illusion: the bright plume following the dark appendage.

Curiously, once Mercury moved away from the Sun's limb, the planet's silhouette appeared as a smeared black dot (like a sunspot's black umbra) surrounded by a rayed shading (like a sunspot's brown penumbra), shown in the third illustration above. American astronomer Percival Lowell observed this same phenomenon during the Mercury transit of November 10, 1894:

"Throughout I noticed that the planet's disk was fringed internally by a penumbra of ray-like character resembling the penumbrae of sunspots. … It was visible under all instrumental and atmospheric conditions. Professor Pickering also saw this but to him it seemed like a light, hazy Band. … He attributes it to superposed images of the planet's disk; to me it appears probably to be an interference effect."

I believe a combination of these two effects with one additional "trick" caused the illusion: the blending of Mercury's dark aureole with the speckled aspect of granulation on the Sun's disk.

The black-drop effect was different at egress. As Mercury approached the Sun's limb, the planet's leading limb stretched into a long, narrow strip. The effect was visible at 23x, but not at 105x, which revealed no black-drop effect at all. Then, as Mercury's trailing limb was about to slip off the Sun's disk, a pale image of the planet appeared beyond the solar limb before vanishing.

By the way, as for the colors that splintered off Mercury's silhouette, they were due to atmospheric dispersion — the simplest magic that light performs in the open air.

E-mail me at someara@interpac.net if you've seen a curious optical phenomenon during a Mercury or Venus transit.

Stephen James O'Meara, *based in Volcano, Hawaii, is a celebrated observer, astronomer, and naturalist, well-known for his acute, sensitive vision of celestial objects.*

Giant loops Yasua Fukui of Japan's Nagoya University and his team report gaseous loops arching above the galaxy's plane form when magnetic field lines are stretched and bent.

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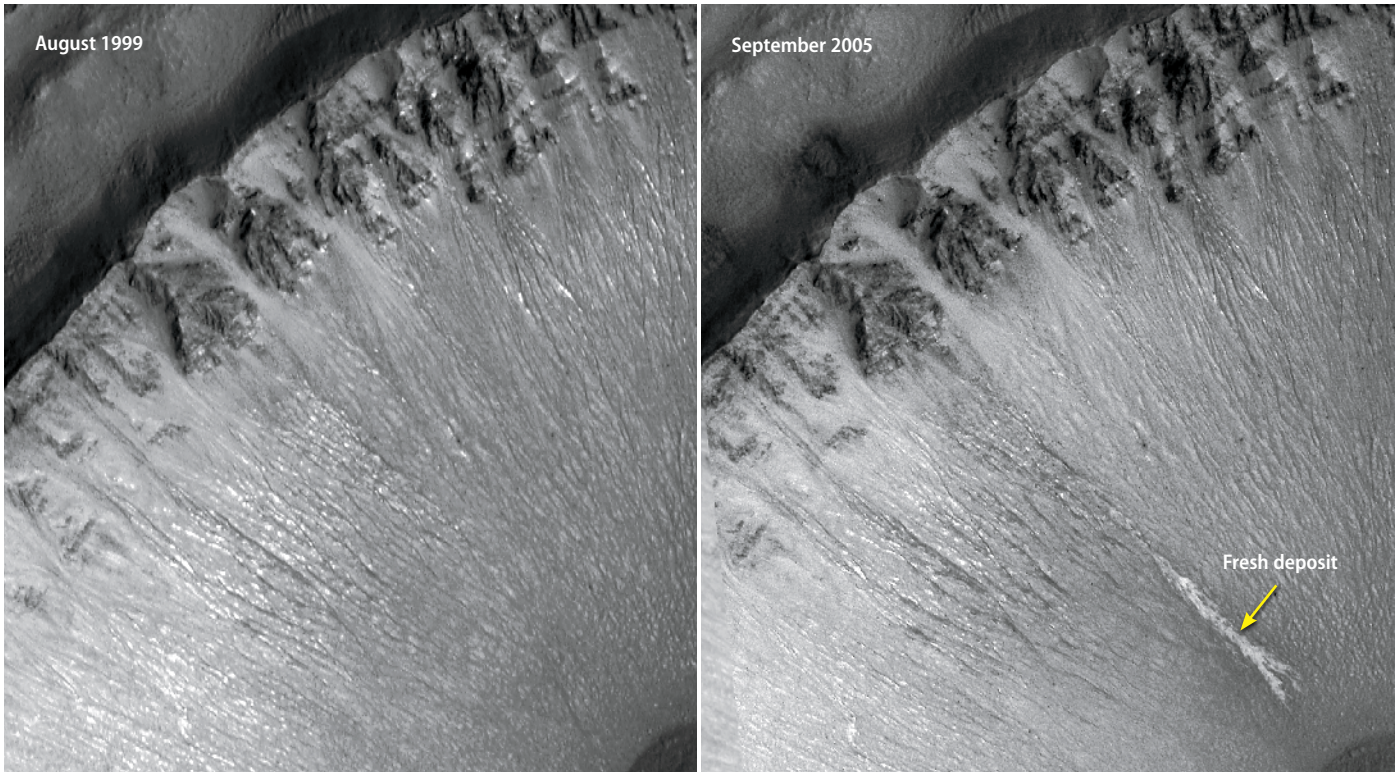

WATERY MARS. Mars Global Surveyor saw a fresh deposit inside this Centauri Montes crater in September 2005. Scientists think the deposit — which didn't appear in an August 1999 image — formed when liquid water briefly flowed on the surface.

22 Asia heads for Mars
23 Supernovae may explode in two stages
24 MRO begins primary science mission
25 Magnetism in a planet-bearing star

Does water flow on Mars today?

Forget about water flowing on *ancient* Mars — scientists reviewing images taken by the Mars Global Surveyor (MGS) spacecraft say it looks like water flows there today. The evidence consists of changes seen in two of the thousands of gullies Global Surveyor has imaged during the past 9 years.

The two sites lie on the sloping walls of craters in the Terra Sirenum and the Centauri Montes regions of southern Mars. Planetary scientists found the water flows by comparing images taken 6 or more years ago with new pictures relayed in the past couple of years.

The two gullies show fresh deposits of light-colored material, each several hundred yards long. "The shapes of these deposits are what you would expect to see if the material were carried by flowing water," says Michael Malin of Malin Space Sciences System, and principal investigator for the MGS camera and lead author of the research that appears in the December 8 issue of *Science*.

Mars' thin atmosphere is too cold for liquid water to exist at the planet's surface for long. The scientists believe the water burst forth from beneath Mars' surface and stayed liquid long enough to carry debris down a slope before freezing.

"This wasn't pure water," emphasizes Malin. "It was most likely water with sediment, probably more like a mud flow."

— IRENE KLOTZ

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DANIEL VERSCHATSE

FAINT GALAXY. Astronomers say this dwarf spheroidal galaxy in Fornax shows our galaxy likely didn't arise from merging dwarfs.

Did dwarf galaxies build the Milky Way?

Cosmologists think small galaxies formed first and later combined to create larger systems like our own. But in the Milky Way's case, that no longer appears to be true.

Amina Helmi of the Kapteyn Astronomical Institute in Groningen, Netherlands, led a team that studied the chemical compositions of more than 2,000 giant stars in the four closest dwarf galaxies to our own galaxy. "The chemistry we see in the stars in these dwarf galaxies is just not consistent with current cosmological models," says Helmi. "It shows that there is plenty of astronomy to learn in our backyard."

The data show the dwarf galaxies' stars and those in the Milky Way's halo have the same average elemental abundances. However, the dwarf galaxies lack the metal-poor stars — those with few elements heavier than helium — seen in the Milky Way.

"Our results rule out any merging of the nearby dwarf galaxies as a mechanism for building up the galactic halo," says Helmi. The team reported its results in the November 10 *Astrophysical Journal Letters*.

— RICHARD TALCOTT

Asia heads for Mars

With China's lunar orbiter (Chang'e 1) scheduled for launch in April and India's own probe (Chandrayaan) tentatively set for liftoff in February 2008, both countries are starting to focus their efforts farther afield — to Mars. China recently reached an agreement to piggyback a probe on a Russian spacecraft less than 3 years from now, and India wants to launch its own Mars-bound spacecraft by 2014.

Last August, Chinese space scientists disclosed that Russia has agreed to carry two sets of Chinese-made science instruments aboard its Fobos-Grunt ("Phobos-Soil") mission, currently scheduled for launch in October 2009.

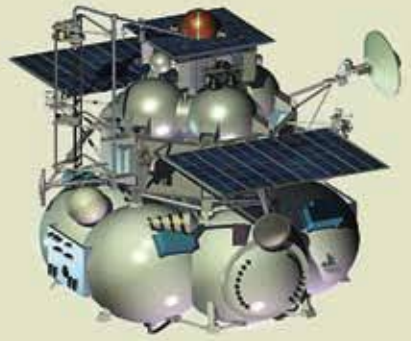
Yuri Nosenko, deputy director of Russia's Federal Space Agency, said Russia invited several countries to take part in its ambitious mission, but only China accepted the invitation.

The Russian probe will be launched into a parking orbit by an upgraded Soyuz-2 booster. Once in low Earth orbit, where it and its remaining fuel will weigh a hefty 18,000 pounds (8,120 kilograms), Fobos-Grunt (FG) will fire its upper stage to begin a 10-month cruise to Mars.

After it reaches the vicinity of Mars, it again will fire its rockets to brake into an orbit that matches the orbital plane of the martian moon Phobos, which nearly matches Mars' equatorial plane. Once at Mars, FG will land on Phobos' surface, collect soil samples, and return them to Earth for laboratory analysis.

China will build a subsatellite named Yinghuo-1 (YH-1) designed to study Mars itself. According to a Russian space agency spokesman, the current best estimate is that YH-1 will weigh several dozen kilograms. Part way through the braking burn that will insert FG into Mars orbit, the subsatellite would be jettisoned. YH-1 would then fly an elliptical, 500- by 50,000-mile equatorial orbit (800 by 80,000 km).

While the FG mother ship maneuvers near Phobos, it would beam powerful radio signals toward YH-1 just at the moments the subsatellite passes in back of, or exits from, Mars. These signals would be used to "sound" the martian ionosphere. YH-1 would receive the attenuated signals broadcast from FG, then, once clear of the atmosphere, retransmit them for analysis back on Earth.



RUSSIAN FEDERAL SPACE AGENCY

FOBOS-GRUNT. This Russian spacecraft will head to Mars in 2010. A Chinese probe named Yinghuo-1 will hitch along, probably with the Earth-return capsule on top.

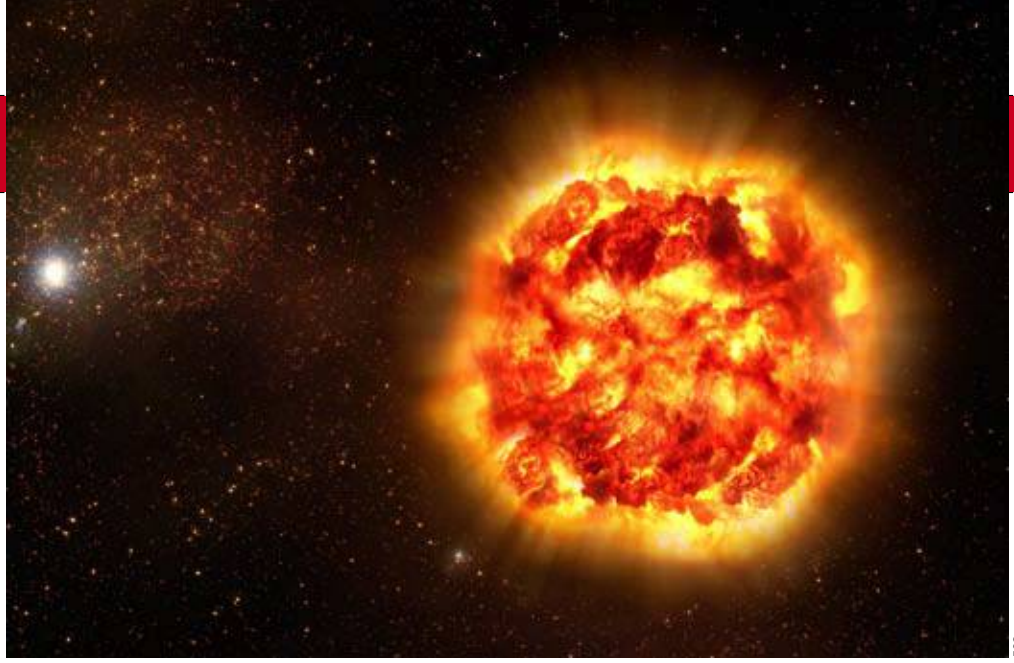
China will spend several million dollars building this spacecraft. It will also pay Russia to communicate with and control the spacecraft — China doesn't yet have enough large tracking antennae with interplanetary reception capability.

Independently, Chinese scientists also will be part of the team fabricating the soil-sampling apparatus for Fobos-Grunt. They will provide an instrument Russia will incorporate into its own spacecraft.

India has higher ambitions for Mars, but will take longer to achieve them — and they will cost a lot more. Late last year, G. Madhavan Nair, the chairman of the Indian Space Research Organisation (ISRO), told a newspaper: "There is a lot of interest in Mars. The missions of the United States and the European Space Agency have given us some interesting data. Let us see what value addition our mission can bring."

India would use a home-grown launch vehicle and its own tracking antennae to support the probe, which would go into orbit around Mars. From there, it will study the chemical attributes of the planet's atmosphere, sub-soil, and terrain, looking for evidence of life. A preliminary budget calls for spending $67 million.

Mars has offered up more than enough mysteries to satisfy the research needs of any and all countries interested in taking part. For China and India, both vying to be the economic and political model for Asia, such a "space race" also makes sense back on Earth. **— JAMES OBERG**



ESO

WHITE-DWARF BLAST. **New research shows the expanding gas shell of a type Ia supernova to be clumpy in its outer regions but smooth in its interior.**

Supernovae may explode in two stages

Astronomers observing distant supernovae have found exploding white dwarfs appear smooth in their inner regions but clumpy in their outer areas. "Our results strongly suggest a two-stage explosion process in this type of supernova," says team leader Lifan Wang of Texas A&M University. Wang, along with Dietrich Baade and Ferdinando Patat of the European Southern Observatory, reported their results November 30 in *Science*.

The team studied 17 type Ia supernovae. Such supernovae result when a white dwarf in a binary system pulls in material from its companion star. As the white dwarf nears a mass of 1.4 Suns, it explodes.

The observed supernovae were so far away, the researchers could not image them in detail. Instead, they studied the polarization of the exploding stars' light. When light scatters through a supernova's expanding debris, it preserves a record of the gas shell's orientation. A spherical shell yields no net polarization, while an out-of-round shell imprints at least some polarization.

Says Baade: "Our study reveals that the outer regions of the blast cloud are asymmetric, with different materials found in clumps, while the inner regions are smooth." Models suggest the clumpiness arises in a slow-burn process called deflagration. The inner regions' smoothness suggests the nuclear-burning gives way to a more violent detonation, which travels so fast it erases any asymmetries left behind by the first stage. **— R. T.**

Where there's smoke…

From its orbital vantage point, the Envisat satellite spied smoke billowing from California's coast October 27. The Esperanza fire produced the smoke in this image, captured with Envisat's Medium Resolution Imaging Spectrometer.

The fire burned about 63 square miles (163 square kilometers) in an area east of Los Angeles before firefighters contained the blaze.

The European Space Agency has compiled an online World Fire Atlas (WFA) from a decade of satellite data. You can access the WFA online at earth.esa.int/rootcollection/eeo9/earth_esa.html. **— LAURA LAYTON**

EUROPEAN SPACE AGENCY

SMOKE ON THE WATER. **ESA's Envisat satellite captured this image of smoke from the Esperanza fire in southern California October 27.**

QUICK TAKES

EARTH'S INNER TURMOIL

Geologist Thorne Lay of the University of California, Santa Cruz, and collaborators used seismic waves generated by 46 earthquakes to probe Earth's core-mantle boundary. The scientists found an environment deep within the mantle that's rife with rock layering and a material that changes from perovskite to post-perovskite. The find, reported in the November 24 *Science*, allows them to measure the heat flow across the core-mantle boundary.

SEAFLOOR ERUPTION

For the first time, scientists at the University of Florida have recorded a volcanic eruption taking place on the seafloor. The spring 2006 eruption happened 400 miles (640 kilometers) off Mexico's coast and some 8,000 feet (2,400 meters) below the ocean surface on the East Pacific Rise.

ONE GIANT LEAP

Neil Armstrong apparently got it right. Computer programmer Peter Shann Ford analyzed an audio file of Armstrong's first words from the Moon. He found the astronaut spoke the "a" in "That's one small step for a man, one giant leap for mankind," but static blotted out the syllable.

ERRANT TEE-SHOT

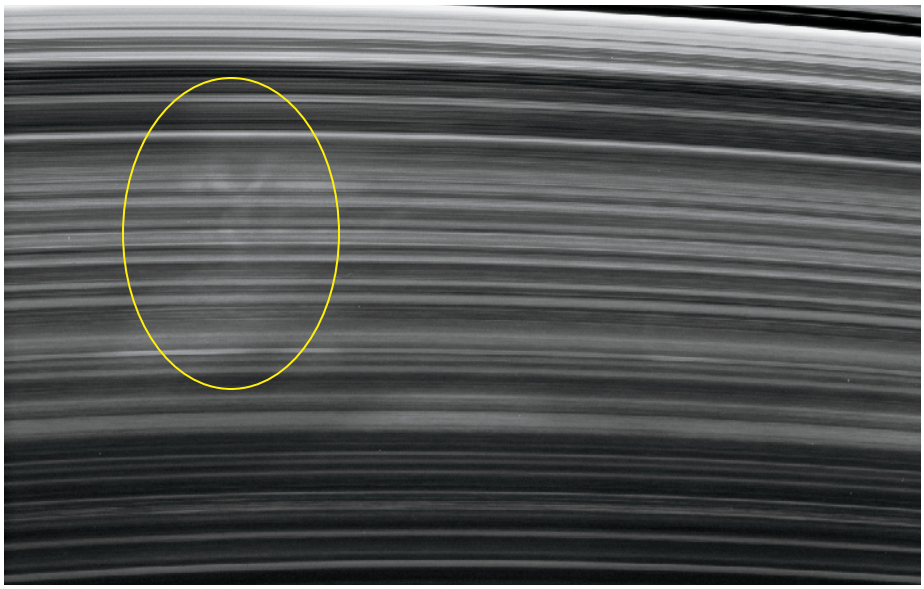
On November 22, Russian cosmonaut Mikhail Tyurin hit a golf shot around the world. With a gold-plated six iron and a one-handed swing, he launched the ultralight ball into orbit. Despite the distance, Tiger Woods should have no worries — Tyurin shanked the shot.

BY THE NUMBERS

An astronomical calculator from 200 B.C. is surprisingly complex, says Michael Edmunds of Cardiff University in Wales. His team used X-ray tomography to study fragments of the Antikythera Mechanism. Scientists think this ancient mechanical computer with more than 30 bronze gears was used to chart astronomical positions. **— L. L.**

Gamma clock

The High Energy Stereoscopic System in Namibia has detected a clocklike gamma-ray signal at an energy 100,000 times higher than any previously known.



NASA/JPL/SSI

RING SPOKE. A ghostly spoke (oval) in Saturn's B ring drifts under the Cassini spacecraft's gaze. Such spokes may result from lightning-induced electron beams.

Lightning may create Saturn's spokes

No one has been able to figure out exactly how the spokes in Saturn's rings develop. These mysterious features, first seen by the Voyager 1 spacecraft in 1980, appear as dark or bright streaks some 60 miles wide (100 kilometers) and up to 12,000 miles long (20,000 km). They build up within a few hours' time and typically dissipate several hours later.

Planetary scientists believe the spokes consist of electrically charged dust grains pushed out of the rings' plane by electrical forces. Now, Geraint Jones of the Max Planck Institute for Solar System Research in Katlenburg-Lindau, Germany, and collaborators propose that lightning in Saturn's mammoth atmosphere creates electron beams that smash into the rings and charge the dust particles. The results were published in the November 9 *Geophysical Research Letters*.

Saturn has strong thunderstorms that generate lightning strokes 10,000 times more energetic than those on Earth. And thunderstorms on Earth can generate electron beams. However, no spacecraft has yet seen such electron beams on Saturn. Scientists with NASA's Cassini mission have started looking for a link between saturnian thunderstorms and ring spokes. — **R. T.**

Making oxygen on early Earth

More than 2 billion years ago, cyanobacteria developed the capacity to release molecular oxygen into Earth's atmosphere. Yet, oxygen production destroys DNA. How could natural selection drive the evolution of poison-protecting enzymes when there was no previous need for them?

A research team led by Danie Liang of Caltech thinks ultraviolet light hitting glacial ice can do the trick. The team reported its findings in the December 12 *Proceedings of the National Academy of Sciences*.

When ultraviolet light strikes water vapor, the radiation converts some of the vapor into hydrogen peroxide and hydrogen gas. Hydrogen peroxide freezes at a temperature just 1° Celsius below water's freezing point. So, during periods of intense glaciation, small amounts of hydrogen peroxide get trapped in the ice.

As the glaciers flow into the ocean, the ice melts, and hydrogen peroxide trickles directly into the seawater. There, another reaction converts the hydrogen peroxide back to water and oxygen. The trickle would allow oxygen-protecting enzymes to evolve without flooding organisms with lethal levels of oxygen. — **R. T.**

MRO begins primary science mission

NASA's Mars Reconnaissance Orbiter (MRO) officially began its science mission November 7. The first color image taken by the spacecraft's High Resolution Imaging Science Experiment (HiRISE) during the science phase shows a small section of a delta that partially fills Eberswalde Crater, which lies in Margaritifer Sinus in Mars' southern hemisphere.

Billions of years ago, water flowed through this delta into a mammoth lake inside the crater. The HiRISE image resolves objects 3 feet across (1 meter). Look closely, and you can see rocks about this size in the delta. They likely were too heavy for the flowing water to move.

"It's been a constant race to look at all these images while we're planning our future targets," says HiRISE principal investigator Alfred McEwen of the University of Arizona's Lunar and Planetary Laboratory. "But it's important to examine the data so we can learn how to use the best possible settings, and make decisions about which targets we'll need to get in stereo or color." Still it's a challenge. "We're trying not to get people too burned out," says McEwen, "but we have to keep up." — **R. T.**

▶ DELTA AFTERNOON. Water once flowed through these channels, which form part of a delta in Eberswalde Crater in Margaritifer Sinus. MRO took this false-color image November 9 at 3:35 P.M. local Mars time, when the Sun was 23° above the horizon.

NASA/JPL/UNIVERSITY OF ARIZONA

March 1982

25 years ago in *Astronomy*

In 1982, the March issue explored the "Secrets of Interstellar Clouds." The hydrogen-rich clouds that hang out between stars are often reworked into a new generation of stars, making them as significant to astronomy as stars themselves.

In a 17-page, stunningly illustrated piece, Laurence Marschall reminded us: "If we ignore the 'space' in our studies, we miss much of the challenge of astronomy." Marschall was right in revealing the importance of interstellar clouds, as they remain an invaluable resource in understanding how stars form.

March 1997

10 years ago in *Astronomy*

The "Great Comet" of 1997 was approaching the Sun in March 1997, so it was no surprise that our cover story that month was "Close Encounters of the Comet Kind." It was co-discoverer Alan Hale's guide to observing Comet Hale-Bopp.

Discovered in 1995, Hale-Bopp became visible to the naked eye during the summer of 1996; came closest to Earth March 22, 1997; and passed perihelion April 1. On March 9, 1997, the Great Comet became the first of these deep-space visitors to remain visible during a total solar eclipse since 1948.

Because of its brilliance and visibility (even from light-polluted cities), Hale-Bopp gained worldwide attention. Although now far below naked-eye visibility, the 19th-magnitude comet remains within the reach of large amateur scopes. — **KATIE NEUBAUER**

MAGNETIC. Astronomers have found a magnetic field on Tau Boötis, a Sun-like star orbited by a hot Jupiter. DAVID AGUILAR (CfA)

Magnetism in a planet-bearing star

Astronomers for the first time have measured directly the magnetic field of a star harboring a "hot Jupiter" — a gas-giant planet orbiting close to its parent star.

A team of astronomers led by Claude Catala of the Paris Observatory observed the star Tau Boötis with the Canada-France-Hawaii Telescope on Hawaii's Mauna Kea. The star, which contains 1.5 solar-masses and lies about 50 light-years from Earth, possesses a magnetic field slightly stronger than the Sun's. The planet weighs 4.4 Jupiters and orbits 4.6 million miles (7.3 million kilometers) from the star, about 5 percent of the Sun-Earth distance.

Astronomers suspect stellar magnetic fields play a key role in producing hot Jupiters. Such a planet likely starts life far from its host star and then migrates inward. The magnetic field may stop the migration and park the planet in a tight orbit. Further observations of similar stars and planets should help make the field's role clearer. The team will report its findings in the *Monthly Notices of the Royal Astronomical Society*. — **R. T.**

BRIEFCASE

MGS gone?

NASA has had no luck contacting the Mars Global Surveyor (MGS) spacecraft. In November, the recently arrived Mars Reconnaissance Orbiter attempted to image MGS, and the Opportunity rover listened for it. Both efforts failed. In December, the Spirit rover planned to cock its ear, and the Mars Express spacecraft expected to target MGS.

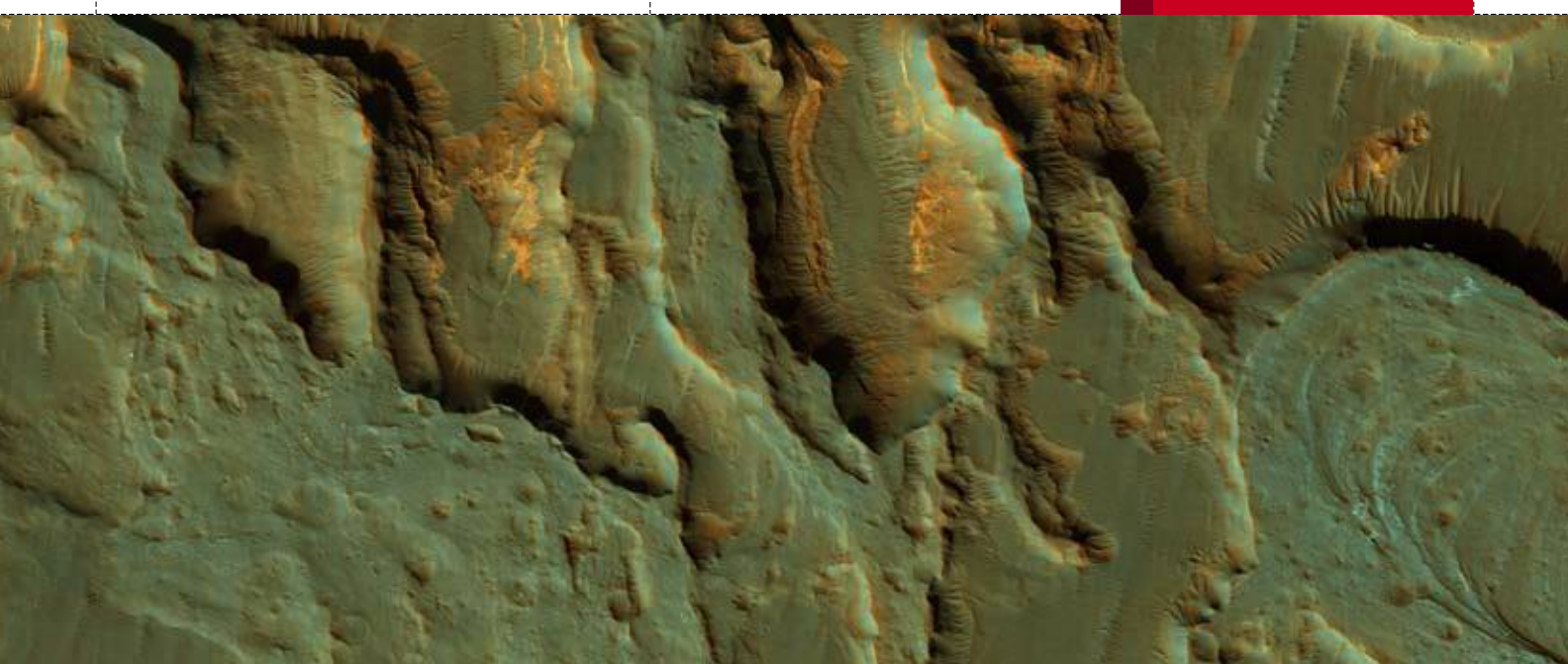
Get a relic

Chicago's Field Museum will let you adopt its Gladstone meteorite for just $25,000. Donors will get their names near the exhibit, along with an original piece of art and mention on the museum's web site.

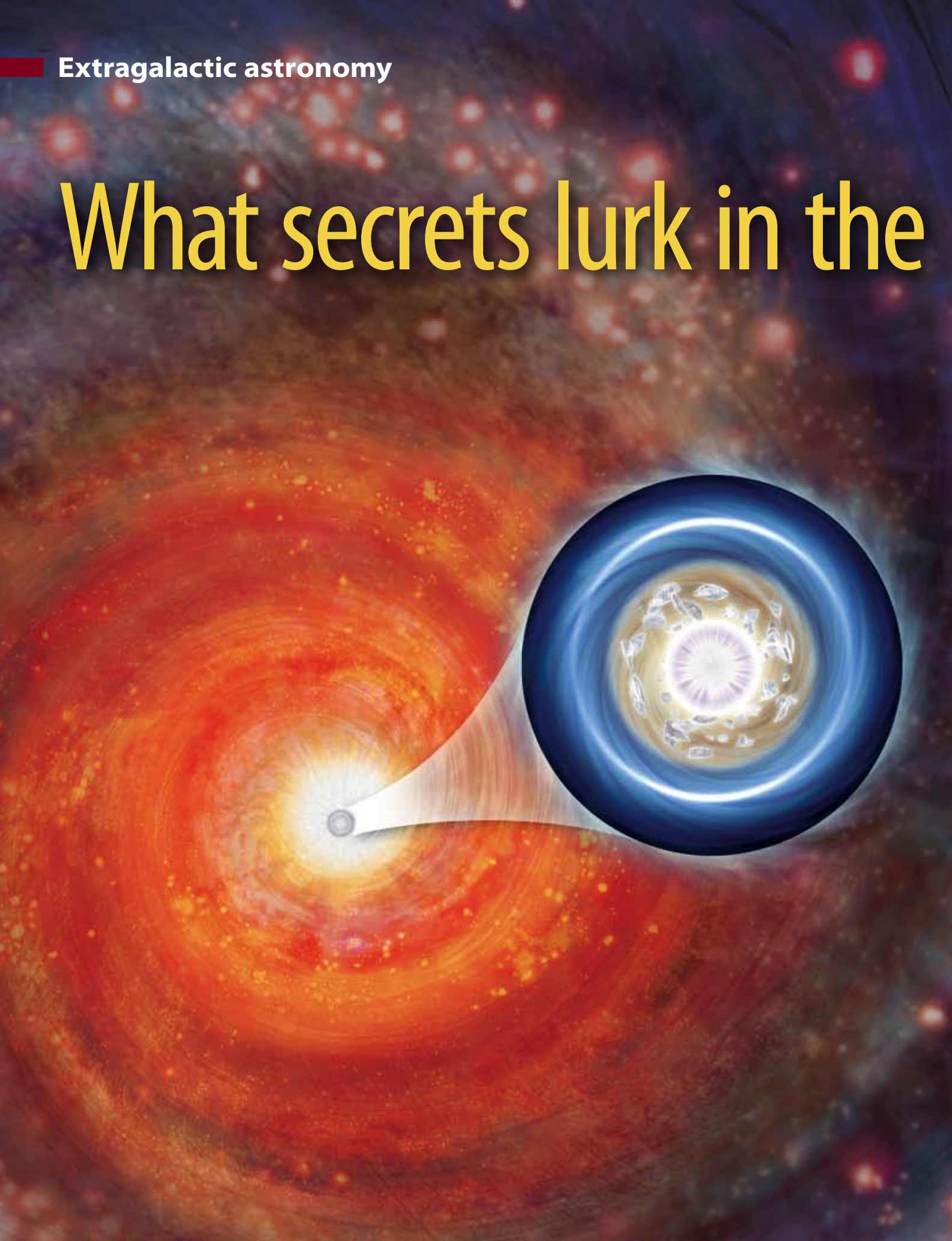
The meteorite is one of 20 exhibits included in the museum's adopt-an-artifact program. Be thankful: A T-Rex skull will cost you $1 million.

Black hole

Astronomers using NASA's Swift satellite and the European Space Agency's INTEGRAL satellite have discovered a black hole near our galaxy's center. The previously unknown source suddenly started emitting gamma-ray pulses as it started to consume gas from its blue-giant companion. — **R. T.**



What secrets lurk in the



ACTIVE GALAXIES viewed head-on appear as blazars, while those viewed edge-on are called Seyfert galaxies.
ASTRONOMY: ROEN KELLY

brightest galaxies?

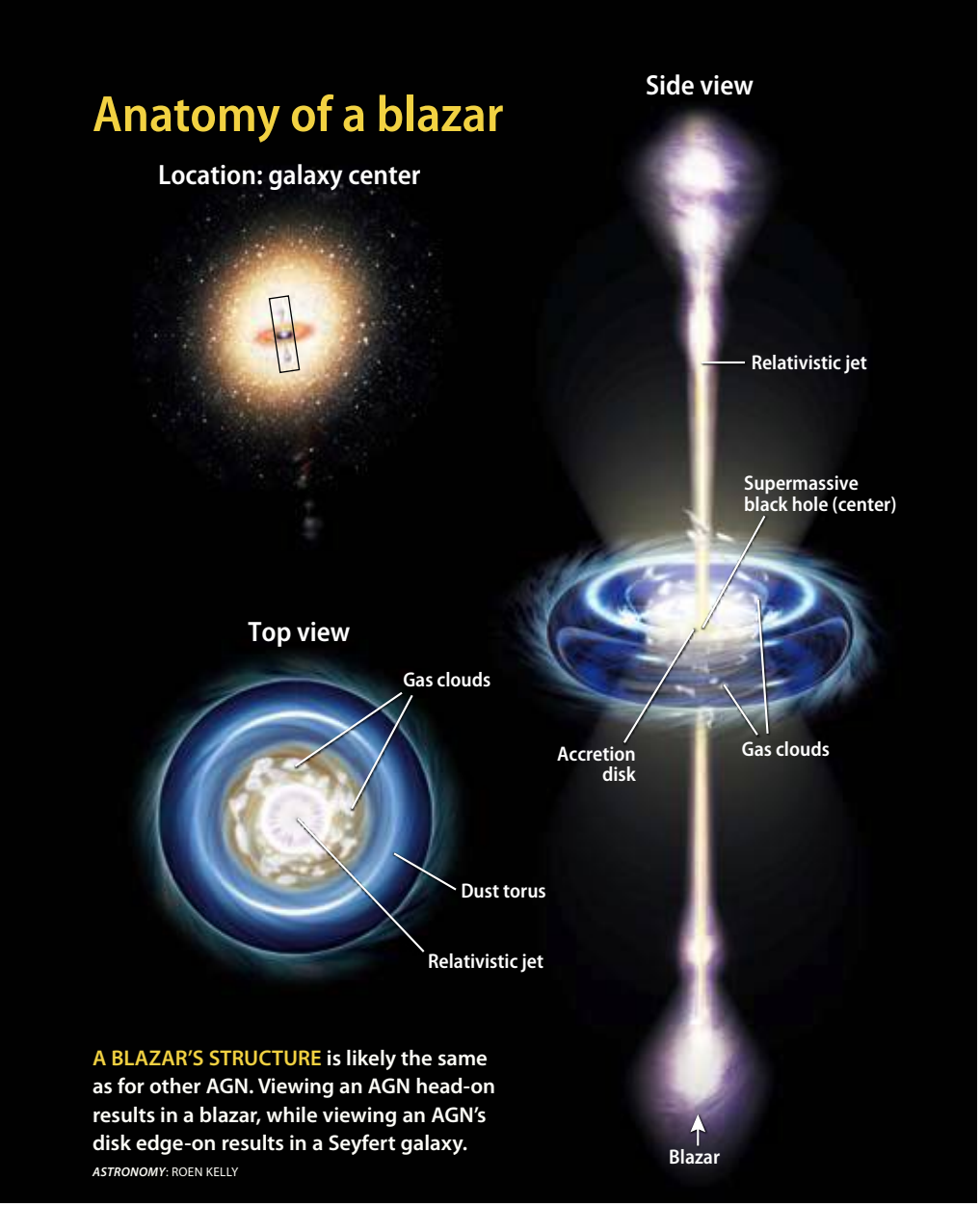
Violent, erratic behavior powers jets within blazars, the most manic galaxies.

/// **BY BRUCE DORMINEY**

Supermassive black holes — possibly millions to billions of times more massive than our Sun — could power active galactic nuclei (AGN) near the fringes of the observable universe. There — where the cosmos is only 10- to 20-percent as old as the total universe — astronomers see brilliant blue quasars and radio-emitting blazars sprinkled among galaxies.

AGN are galaxies with compact, active central cores that emit considerably more energy than do the galaxy's stars, gas, and dust. AGN come in three main types: Seyfert galaxies, quasars, and blazars.

Bruce Dorminey, *a science journalist and author of* Distant Wanderers: The Search for Planets beyond the Solar System *(Springer-Verlag, 2002), is host of "Cosmic Cast," an Internet-based, astronomy-related talk show at cosmiccontroversy.com.*



A BLAZAR'S STRUCTURE is likely the same as for other AGN. Viewing an AGN head-on results in a blazar, while viewing an AGN's disk edge-on results in a Seyfert galaxy. *ASTRONOMY:* ROEN KELLY

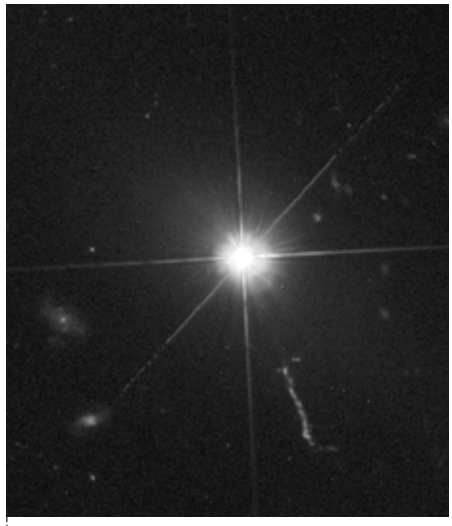
All three emit high-energy radiation, but subtle differences separate these subgroups. Seyfert galaxies have broad and narrow emission lines. Quasars are the most consistently bright. Blazars emit in the radio part of the spectrum and show great changes in brightness.

Blazars take their name from a combination of the terms "BL Lacertae" and "quasar." Astronomers divide blazars roughly into two groups: lower-energy, relatively nearby BL Lacertae objects and higher-energy, distant sources. More than 1,000 blazars have been cataloged. All blazars are intense radio sources, optically polarized, and vary in brightness — with fluctuations ranging from minutes to years. Some blazars — likely the most energetic active galaxies in the cosmos — are nearly 1,000 times more luminous than a typical galaxy. Theorists believe solar-system-sized black holes power their central cores.

"All AGN are thought to have a supermassive black hole at their center, an accretion disk around it, and a relativistic jet perpendicular to the accretion disk," says Richard Miller of Georgia State University in Atlanta. Highly energetic photons within blazars arrange themselves into jets that blast forth perpendicular to the plane of their host galaxies and span hundreds of thousands of light-years. When seen along our line of sight, blazars' energetic beams appear amplified. Charged particles are collimated into beams that move at nearly light-speed.

It's a matter of perspective

While the three main types of AGN differ somewhat, one theory suggests their differences arise only from different observation angles. Thus, how astronomers classify an object with a compact energy source within its nucleus may be only a matter of perspective.

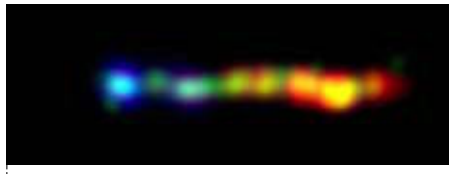


QUASAR 3C 273 shines brightly in this Hubble Wide-Field Planetary Camera 2 optical image. NASA/J. BAHCALL

Miller says, "The jet and counter jet will move in two directions. Depending upon how you happen to view that object, you would call it either a blazar or quasar. Looking down the throat of the relativistic jet, you will call that object a blazar." Blazars' true nature is still a topic of debate among astronomers.

If blazars are AGN with a jet pointing toward Earth, then a prejudicial selection effect exists in the way we view blazars. Scientist James Webb thinks we may be missing as many as hundreds of thousands of AGN that could have blazar-like high-energy relativistic jets. Webb is a physics professor at Florida International University in Miami and a longtime blazar observer.

One theory predicts the central engine of a supermassive black hole accreting infalling gas powers blazars. The black hole's massive gravitational force heats and



A MASS OF PARTICLES is ejected from quasar 3C 273 in this edge-on view. This relativistic jet spans more than 100,000 light-years. Quasars and blazars may be the same kind of objects viewed from different angles. NASA/JPL-CALTECH/YALE UNIV.

THE FIRST BLAZARS

International optical monitoring groups have studied blazars since the 1970s, taking data and plotting light curves. The first observed blazars were initially misidentified as variable stars due to their changing brightnesses. Because blazars' brightness fluctuations have no periodicity, astronomers soon realized these objects are more exotic than variable stars.

Although astronomers have observed variable object BL Lacertae (located in the constellation Lacerta) since the late 1920s, another 40 years passed before a powerful extragalactic radio source was identified in addition to its optical component. Ten years later, astronomers theorized BL Lac, as it is commonly known, has relativistic jets pointing along our line of sight. It thus became known as a weak, or minimal, blazar of the BL Lac class, with a star-like appearance, but unresolved in visible light.

Astronomers believe M87, a relatively nearby giant elliptical galaxy at the center of the Virgo cluster, is a misaligned BL Lac blazar whose jet was first observed in 1918.

ACTIVE GALAXY M87 in the Virgo cluster shows blazar-like features, including a relativistic jet, gas disk, and a compact nucleus. H. FORD (STScI/JHU)/R. HARMS (ARC)/Z. TSVETANOV, A. DAVIDSEN, G. KRISS (JHU)/R. BOHLIN, G. HARTIG (STScI)/L. DRESSEL, A. KOCHHAR (ARC)/B. MARGON (UWS)/NASA

M87 features several characteristics consistent with blazars. Astronomers observe blazars in elliptical galaxies, and M87 is a giant elliptical galaxy. Blazars have relativistic jets, as does M87. And active galaxies where astronomers observe blazars harbor compact energy sources, most likely supermassive black holes, at their cores. — *B. D.*

compresses this gas. Magnetic fields wind up along the poles of the rotating system, creating a force that pinches high-energy particles into beams capable of escaping from near the black hole's event horizon, the boundary where a particle's escape velocity equals the speed of light.

Another theory points to black-hole mergers as the power behind blazars. In 1988, astronomers at Finland's Tuorla Observatory saw periodicity in their data on BL Lac object OJ 287. They believe this indicates OJ 287 shows double-peaked outbursts roughly every 12 years, which possibly signals a binary black-hole system. Because the object lies close to our ecliptic plane, astronomers unwittingly have photographed the galaxy since 1893. Analyses of old photographic plates provide a long record, revealing the object's 12-year cycle back to 1910. OJ 287's last double outburst came in 1994–1995.

If these are two supermassive black holes caught in the act of merging, the discovery is serendipitous, to say the least, and it strikes some scientists as altogether unlikely.

Mauri Valtonen of the University of Turku in Finland is not easily dissuaded from his model of a supermassive black-hole binary. Valtonen estimates there are thousands of objects similar to OJ 287 yet to be discovered.

"Most, if not all, supermassive black holes today have their origins in this early cosmological buildup of black-hole mass, which comes partly from mergers of black holes and partly from growth by accretion of gas," says Valtonen.

But Webb questions current OJ 287 binary models. He finds it difficult to imagine that a second massive black hole could actually move through a primary black hole's accretion disk and generate outbursts without destroying the entire system.

Missing link or anomaly

Theorists have long debated whether blazars represent a missing link in galaxy evolution or merely an anomalous galactic *cul de sac* that frequently pops up in dense galaxy clusters at high redshifts. Webb believes the former: Blazars are part of the

ENERGY SPEAK

ACTIVE GALACTIC NUCLEUS (AGN)
A galaxy with a compact emission source — probably a supermassive black hole — at its core. AGN types include blazars, quasars, and Seyfert galaxies.

BL LACERTAE OBJECT
This type of AGN is one of two blazar subclasses. BL Lac objects, as astronomers commonly refer to them, fluctuate rapidly in brightness, display polarized visible light, and they are less luminous than quasars.

BLAZAR
A term coined by American astronomer Ed Spiegel combining "BL Lacertae" and "quasar." Blazars are a subset of quasars noted for their intense brightnesses — up to 1,000 times brighter than a typical galaxy — and their variability, with fluctuations ranging from seconds to years. Only elliptical galaxies host blazars.

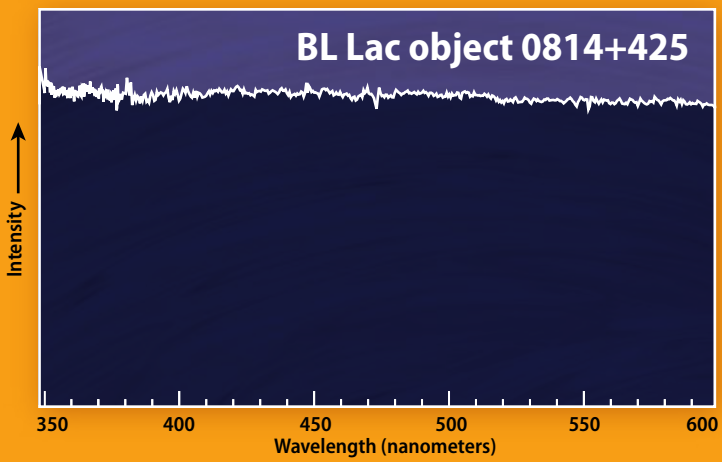
QUASAR
A bright, distant quasi-stellar radio source that emits copious amounts of energy from its compact core, where a supermassive black hole presumably exists.

RELATIVISTIC JET
Subatomic particles moving near light-speed, ejected as a black hole feeds on infalling matter; powerful magnetic fields focus this plasma into narrow beams.

SEYFERT GALAXY
A spiral or irregular galaxy with an active core less than 1 light-year across that fluctuates in brightness.

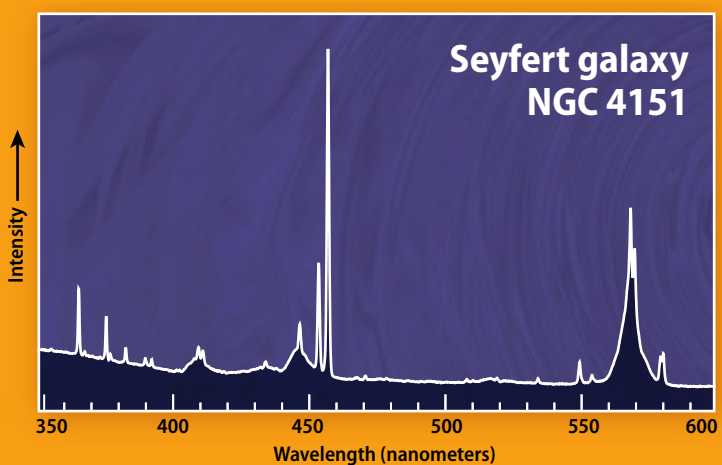
SUPERMASSIVE BLACK HOLE
A black hole with hundreds of thousands to tens of billions of solar-masses.

Spectra fingerprint AGN types



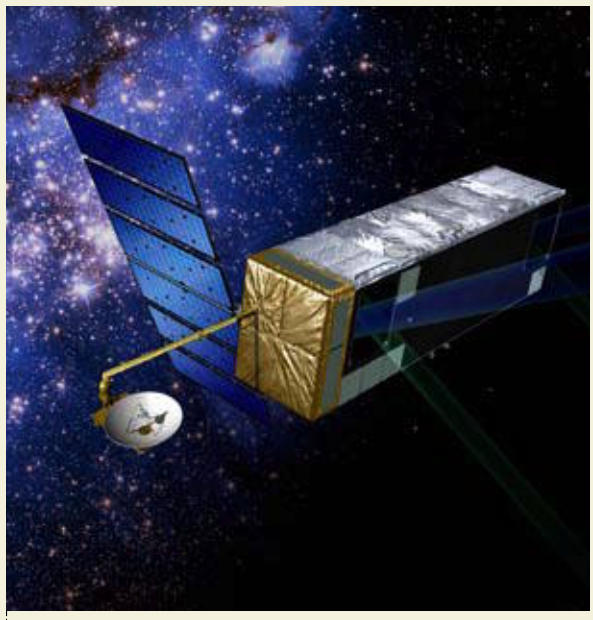
BLAZAR 0814+425, a BL Lac object, maintains intensity across the visual part of the electromagnetic spectrum. P. FRANCIS (AUSTRALIAN NATIONAL UNIV.)/W. KEEL (UNIV. OF ALABAMA)/C. LAWRENCE (JPL)/R. KENNICUTT (CAMBRIDGE UNIV.)

QUASARS show higher intensity at smaller wavelengths and become less intense at longer wavelengths with a high-intensity peak at 500 nm. R. KENNICUTT (CAMBRIDGE UNIV.)/W. KEEL (UNIV. OF ALABAMA)/C. LAWRENCE (JPL)/P. FRANCIS (AUSTRALIAN NATIONAL UNIV.)



SEYFERT GALAXY NGC 4151 is significantly less intense than either blazars or quasars and shows a peak intensity near 450 nm.

R. KENNICUTT (CAMBRIDGE UNIV.)/W. KEEL (UNIV. OF ALABAMA)/C. LAWRENCE (JPL)/P. FRANCIS (AUSTRALIAN NATIONAL UNIV.)



THE SIM SPACECRAFT is a space-based interferometer that will measure distances to nearby stars and search for Earth-sized exoplanets around them. NASA/JPL-CALTECH

WHAT'S NEXT IN BLAZAR EXPLORATION?

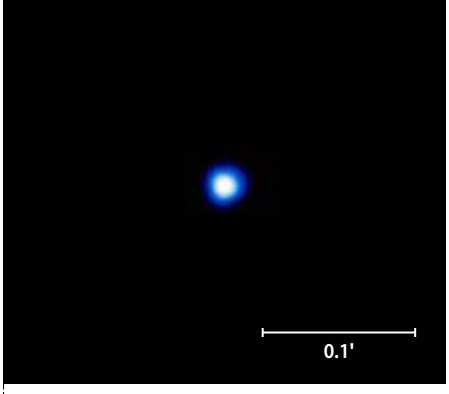
NASA's Space Interferometry Mission (SIM), a mission due to launch no earlier than 2011, will hunt for extrasolar planets and search for direct evidence of binary black-hole systems. Studying these active galaxies will help astronomers learn more about blazars' structure.

NASA's Gamma Ray Large Area Space Telescope (GLAST) is scheduled for an August 2007 launch. GLAST's Large Area Telescope (LAT) is slated to cover more than 20 percent of the sky every 3 hours. Such a large field of view will allow researchers to monitor thousands of blazars regularly. And NASA is already trying to organize ground-based, multiwavelength coverage to follow up on the blazars GLAST will likely find.

"With its high sensitivity and wide field of view, GLAST's Large Area Telescope (LAT) will allow daily measurements of blazar gamma-ray radiation," says Dave Thompson, an astrophysicist at NASA's Goddard Space Flight Center in Baltimore. "Understanding the jet mechanism is critically dependent on multiwavelength, time-resolved modeling. GLAST will provide high-quality gamma-ray data with time resolution down to hours. And LAT will allow direct measurements to determine why so few blazars extend to higher energies."

Future X-ray and ultraviolet astronomy missions will seek a better understanding of the detailed processes of how jets form from black holes. These missions will also explore the physical relationships among a black hole's accretion disk, the event horizon, and the outflow of relativistic particles.

X-ray observations of elliptical galaxy M87 revealed an accretion disk, and researchers are still looking for an observational link between M87's disk and jets. — *B. D.*



BLAZAR MARKARIAN 421 in Ursa Major is one of the closest BL Lacertae objects. This 13th-magnitude gamma-ray blazar is also the brightest. NASA/SAO/CXC/F. NICASTRO ET AL.

evolutionary link between early galaxies and more evolved galaxies.

"Blazars are probably forming at all redshifts, but they seem to be very long-lived phenomena," says Yale University astronomer Megan Urry. "Once you generate one of these jets, it's not easy to turn them off. Even if you did turn them off, the flow continues, and the electrons continue to radiate in the radio spectrum for hundreds of millions of years. So they may last only a fraction of the age of the universe, but it's not a negligible fraction."

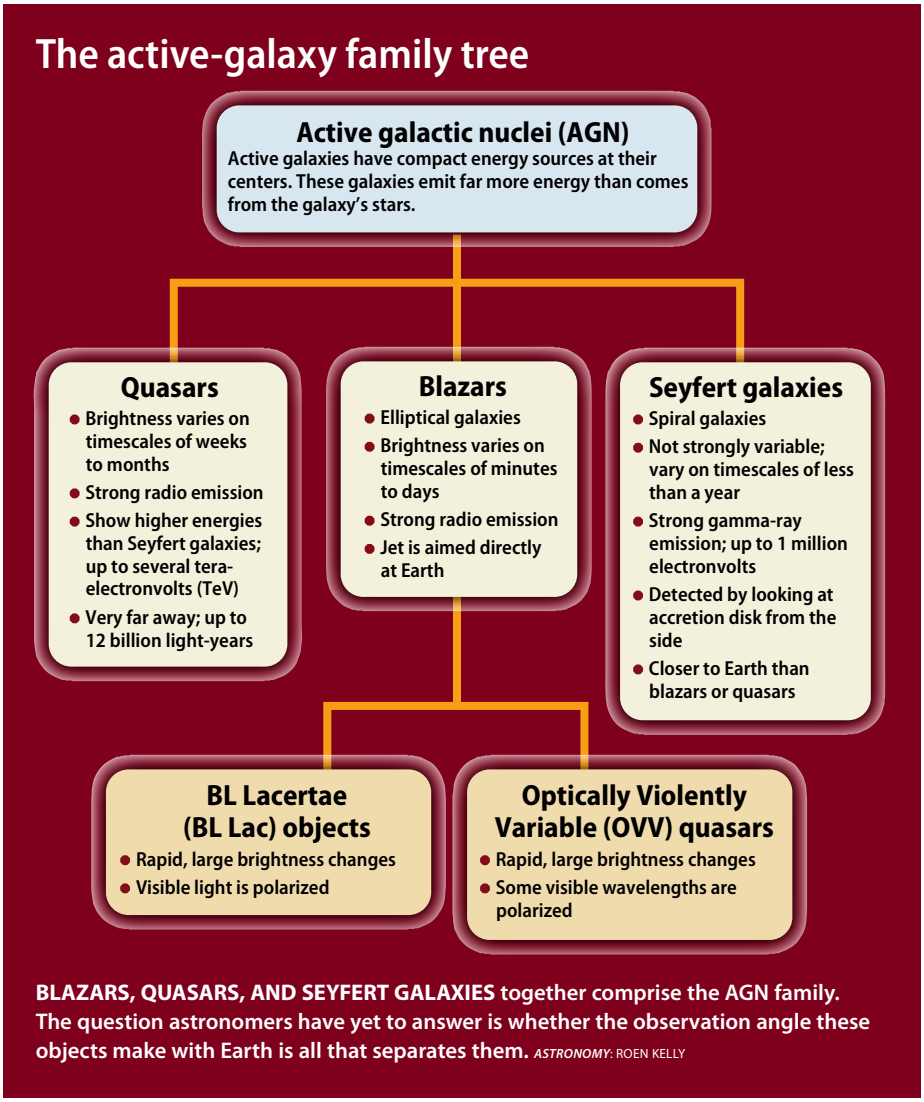
Elliptical galaxies and blazars

Elliptical galaxies may hold the key to blazar formation. Because elliptical galaxies don't have dense interstellar gas and dust, a powerful jet can punch its way through the galaxy and form a large radio source. Even powerful jets might not be able to pierce the dense interstellar medium of a spiral galaxy. Thus, in elliptical galaxies, blazars are most likely the products of violent galactic collisions, which would explain why they are seen more often in galaxy clusters.

"The most luminous active galactic nuclei seem to have been formed in collisions of galaxies," says Charles Dermer, a gamma-ray astronomer at the Naval Research Laboratory in Washington. "Our Milky Way had an active galactic nucleus, but because we did not have this kind of catastrophic collision with another galaxy, we did not have the quasar-style active galactic nucleus."

Our own Milky Way galaxy is radio-quiet, meaning it doesn't emit strongly at radio wavelengths. Astronomers believe this is because its central black hole is too small to have generated a high-energy quasar. Scientists still debate whether the Milky Way once had quasar activity.

The active-galaxy family tree


Active galactic nuclei (AGN)
Active galaxies have compact energy sources at their centers. These galaxies emit far more energy than comes from the galaxy's stars.
Quasars
Brightness varies on timescales of weeks to months
Strong radio emission
Show higher energies than Seyfert galaxies; up to several tera-electronvolts (TeV)
Very far away; up to 12 billion light-years
Blazars
Elliptical galaxies
Brightness varies on timescales of minutes to days
Strong radio emission
Jet is aimed directly at Earth
Seyfert galaxies
Spiral galaxies
Not strongly variable; vary on timescales of less than a year
Strong gamma-ray emission; up to 1 million electronvolts
Detected by looking at accretion disk from the side
Closer to Earth than blazars or quasars
BL Lacertae (BL Lac) objects
Rapid, large brightness changes
Visible light is polarized
Optically Violently Variable (OVV) quasars
Rapid, large brightness changes
Some visible wavelengths are polarized

BLAZARS, QUASARS, AND SEYFERT GALAXIES together comprise the AGN family. The question astronomers have yet to answer is whether the observation angle these objects make with Earth is all that separates them. *ASTRONOMY:* ROEN KELLY

Astronomers observe blazars in black-hole systems with high accretion rates. This may suggest the black hole that powers a blazar is larger than the one in our own galaxy. Blazars transform accreting matter into energetic outflows, somewhat like giant particle accelerators. Some accreting material escapes the clutches of the black hole and forms jets. But researchers are still trying to come to terms with the underlying power of these relativistic jets. Scientists don't yet understand how these jets form.

Part of the solution to this conundrum may lie in these objects' micro-variability, over timescales of only minutes. "Magnetic flares on the accretion disk may periodically flare up and cause these increases in brightness," says Webb. "Another possibility is that as shock waves propagate out through the jet, the micro-variability may be caused by differences in density, differences in magnetic fields."

New insight, more questions

"Blazars point us to the earliest epochs of structure formation," says Dermer. "In this business, you go where the light is, where the brightest sources are. Those brightest sources tend to be fueled by black holes. Blazars offer a unique black-hole laboratory, a way to chart structure formation in time, a bright light to look at the distant universe."

Learning more about blazars will lead to new insights on galaxy formation during the universe's earliest times. Recent deep-galaxy surveys find massive and evolved galaxies at the highest redshifts. Because these distant objects contain supermassive black holes, Webb believes they must also be the seeds for galaxies.

But the question remains: How did such massive black holes form in so short a time? Astronomers will endeavor to answer this question and others about the nature of blazars and their place in the cosmological scheme of things.

Raising the curtain on

Superdense neutron stars show astronomers exotic worlds of pressure, magnetism, and gravity.

/// BY TOD E. STROHMAYER

For astrophysicists, a neutron star is the ultimate cosmic laboratory. Just a dozen or so miles across, these objects are the crushed cores of stars that collapsed and exploded. A teaspoon of neutron-star matter weighs upwards of a billion tons, more mass than all of humanity. Nowhere else can scientists study matter under such extreme conditions. The density, pressure, magnetism, and gravity found in a run-of-the-mill neutron star far exceed any research lab's capabilities.

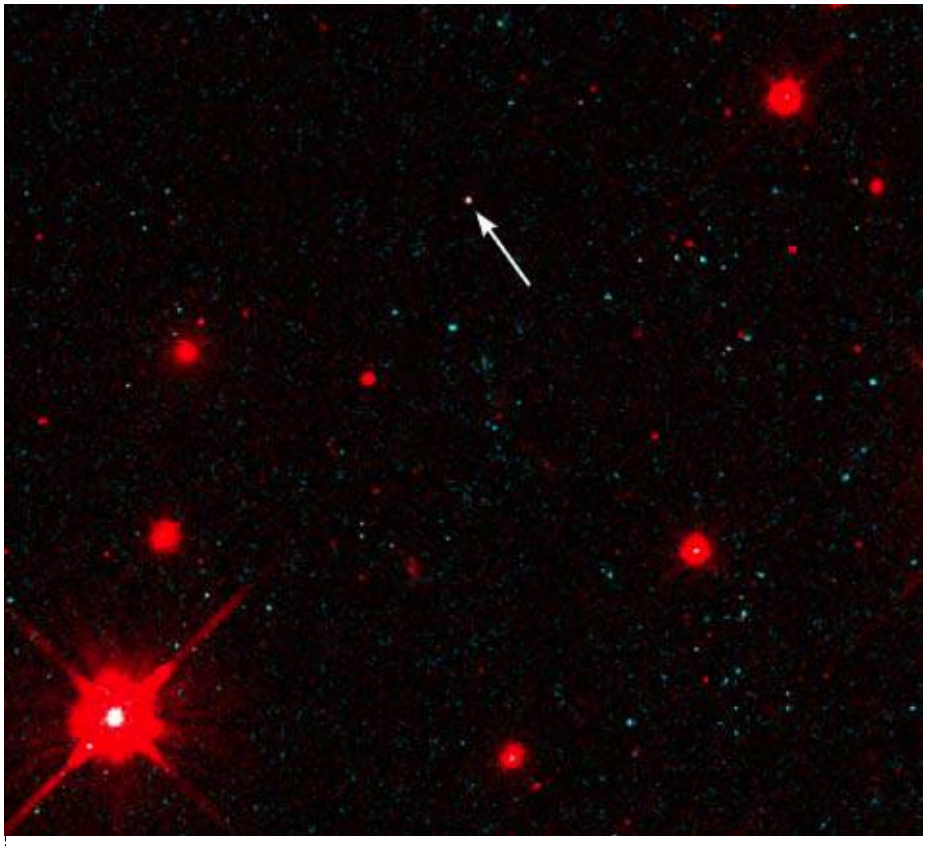
Isolated neutron stars don't easily reveal their secrets. But when a neutron star orbits and interacts with another star, the stage is set for explosive fireworks that expose these compact objects. In a tight binary system, the neutron star's gravity can draw matter from its companion star in a process astrophysicists call accretion. The orbital periods in which accretion can take place depend on the mass of the neutron star and its companion and can range from hours to minutes. Indeed, the most compact neutron-star binary system known, 4U 1820–30, has an orbital period of just 11 minutes. The entire system easily would fit between Earth and the Moon.

When matter falls toward a massive body, it accelerates, gaining kinetic energy. Just how much it gains depends on how much mass the accreting object packs into how small a volume. For a neutron star, where a mass greater than the Sun is crushed into a ball just 12 miles (20 kilometers) wide, the amount of energy released is truly phenomenal — about 30 times greater, per unit of mass, than the energy produced by the

DISTORTED by their mutual attraction, a pair of orbiting neutron stars begins to merge. Swirls of matter where the two stars contact one another dramatically amplify magnetic fields. The event will launch a gamma-ray burst detectable across several billion light-years.

DANA BERRY FOR *ASTRONOMY*

extreme stars



THE CLOSEST known neutron star is RX J185635–3754 (arrow), an isolated specimen 380 light-years away imaged with the Hubble Space Telescope in 1997. Neutron stars are among the universe's most exotic objects. NASA/F. WALTER (SUNY, STONY BROOK)

nuclear fusion in the Sun's center. Black holes do even better.

The infalling matter releases its kinetic energy when it strikes the neutron star. This heats the star and its immediate environs to temperatures in excess of 10 million Kelvin. At these temperatures, matter radiates energy predominantly as X rays, so these objects are known as X-ray binaries. Nobel Prize winner Riccardo Giaconni found the first such object during a 1962 rocket experiment. Called Scorpius X-1, the system is still the sky's brightest persistent X-ray source. Because Earth's atmosphere strongly absorbs X rays, we can observe these systems only from space.

High mass, low mass

In the Milky Way, astronomers have cataloged several hundred X-ray binaries in which the compact object is either a neutron star or a black hole. These systems fall into two classes. High-mass X-ray binaries (HMXBs) feature a donor star that's massive and young. Low-mass X-ray binaries (LMXBs) have older, lower-mass donors.

The number of X-ray binaries discovered is a tiny fraction of the galaxy's hundreds of billions of stars, which attests to the difficulty of forming such pairs. For starters, one of the stars must be massive enough to form a neutron star in a supernova explosion — a feat that likely requires a star of at least 8 solar-masses. Relatively few such stars are born.

Next, the system must survive the massive star's explosion. In many cases, the powerful blast sends both stars flying off into the galaxy. And even if the binary system remains intact, the stars must be close enough to evolve into an accreting system. The small number of systems we know isn't so surprising given the number of unlikely steps required to make them.

EVERY postage-stamp-sized patch of the neutron star's surface explodes with the energy of a hundred 15-megaton bombs.

Matter flows from the donor star in a mass-loss stream. Because the stars move relative to one another, and because the neutron star is so much smaller than its companion, this stream doesn't fall directly onto the neutron star. Instead, it goes into orbit around the star, and accumulates in an accretion disk. Matter in this disk spirals slowly inward, releasing gravitational energy and heating up before eventually plunging onto the surface.

The accretion process itself is chaotic, and matter can accumulate in the disk for years before taking the final plunge onto the neutron star. This makes X-ray binaries highly variable. They can suddenly flare up from obscurity in bright outbursts that can last from weeks to years.

Astronomers call such sources X-ray transients or X-ray novae. If the neutron star has a strong enough magnetic field, it will guide infalling matter preferentially toward the magnetic poles. The resulting non-uniform accretion can produce an X-ray pulsar if the star's rotational poles don't line up with its magnetic poles. A high-energy beam then sweeps across the sky like a deadly lighthouse. Among HMXBs, which often have young neutron stars hosting strong magnetic fields, X-ray pulsars occur frequently.

Spin up

If the neutron star's magnetic field is relatively weak — the case in most LMXBs — the disk's inner edge can approach the star's surface. It orbits at a frenetic pace — almost half the speed of light — racing around the star more than 1,000 times each second. This whirling material has a lot of angular momentum, which it imparts to the star and "spins" it up.

While the kick from any single bit of accreted matter is small, the effect accumulates over hundreds of millions of years. (Some LMXBs are a billion years old or more.) In fact, not long after the 1962 discovery of accreting neutron stars, astronomers suspected rapid spins of up to 1,000 revolutions each second. Twenty

Tod E. Strohmayer *is an astrophysicist specializing in X-ray timing studies at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

years later, the discovery of millisecond radio pulsars supported the spin-up idea. Only in the last decade, however, have astronomers gathered direct observational evidence — but more on this later.

Neutron bomb

What becomes of the matter accreted by a neutron star? The stellar material is rich in light elements, with hydrogen and helium being the most abundant ones. It piles up on the neutron star's surface in a layer that becomes hotter and more compressed by the constant rain of material. If the material piles up at just the right rate, it eventually will reach sufficient density and temperature to trigger a thermonuclear runaway.

In a matter of seconds, hydrogen and helium fuse into a complex soup of heavy elements. The reactions release a prodigious amount of energy — every postage-stamp-sized patch of the neutron star's surface explodes with the equivalent energy of more than a hundred 15-megaton thermonuclear bombs. This rapid energy release heats the surface to several billion Kelvin and causes it to glow in X rays.

At their peak, these so-called X-ray bursts can shine with the brightness of 100,000 Suns, but the show lasts no longer than 20 seconds. Amazingly, these events typically recur every few hours, after a new layer of fuel accumulates to set off the next stellar conflagration.

Astronomers know of about 80 accreting LMXB neutron stars that produce X-ray bursts. Because we see strong X-ray emission directly from the neutron-star surface during these bursts, these systems provide a powerful tool for studying neutron stars.

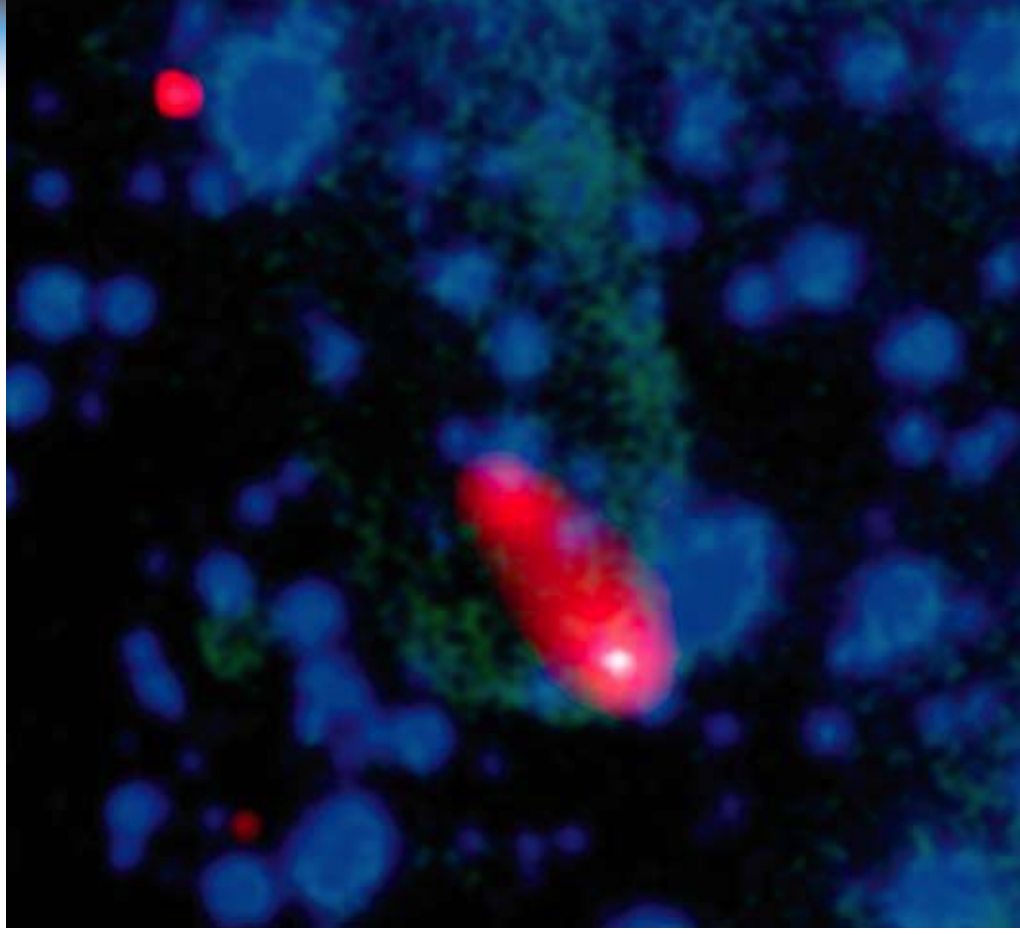
Rossi revolution

In December 1995, NASA launched the Rossi X-ray Timing Explorer (RXTE), an orbiting X-ray observatory that has revolutionized our understanding of neutron-star binaries. While RXTE doesn't make high-resolution images like NASA's Chandra X-ray Observatory, it precisely measures how X-ray sources flicker and pulsate in less than a millisecond. We now know neutron stars display astronomy's fastest pulsations.

Before RXTE, astronomers believed accreting neutron stars would spin rapidly, but attempts to directly measure spin rates came up empty. RXTE combines a large telescope aperture, the ability to sense rapid changes, and the data-handling capabilities to make such observations routine.

RXTE observations allow us to directly see that many LMXB neutron stars rotate at dizzying speeds, some as fast as 620 times a second (620 Hertz). The first indications of very high spin rates came in early 1996. Some accreting neutron stars pulsate rapidly during X-ray bursts, a phenomenon now known as burst oscillations. My colleagues at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and I found the first example of this behavior in the LMXB system 4U 1728–34, which pulsates at 363 Hertz. Subsequent observations of burst oscillations in other LMXBs showed they had a frequency between 300 and 600 Hz, a range consistent with theoretical predictions for spin-up by accretion.

Strong pulsations occur only during X-ray bursts because the accreted matter detonates at a particular location on the neutron star's surface. The thermonuclear "flame" spreads and then engulfs the entire star. If the star rotates faster than the time it takes



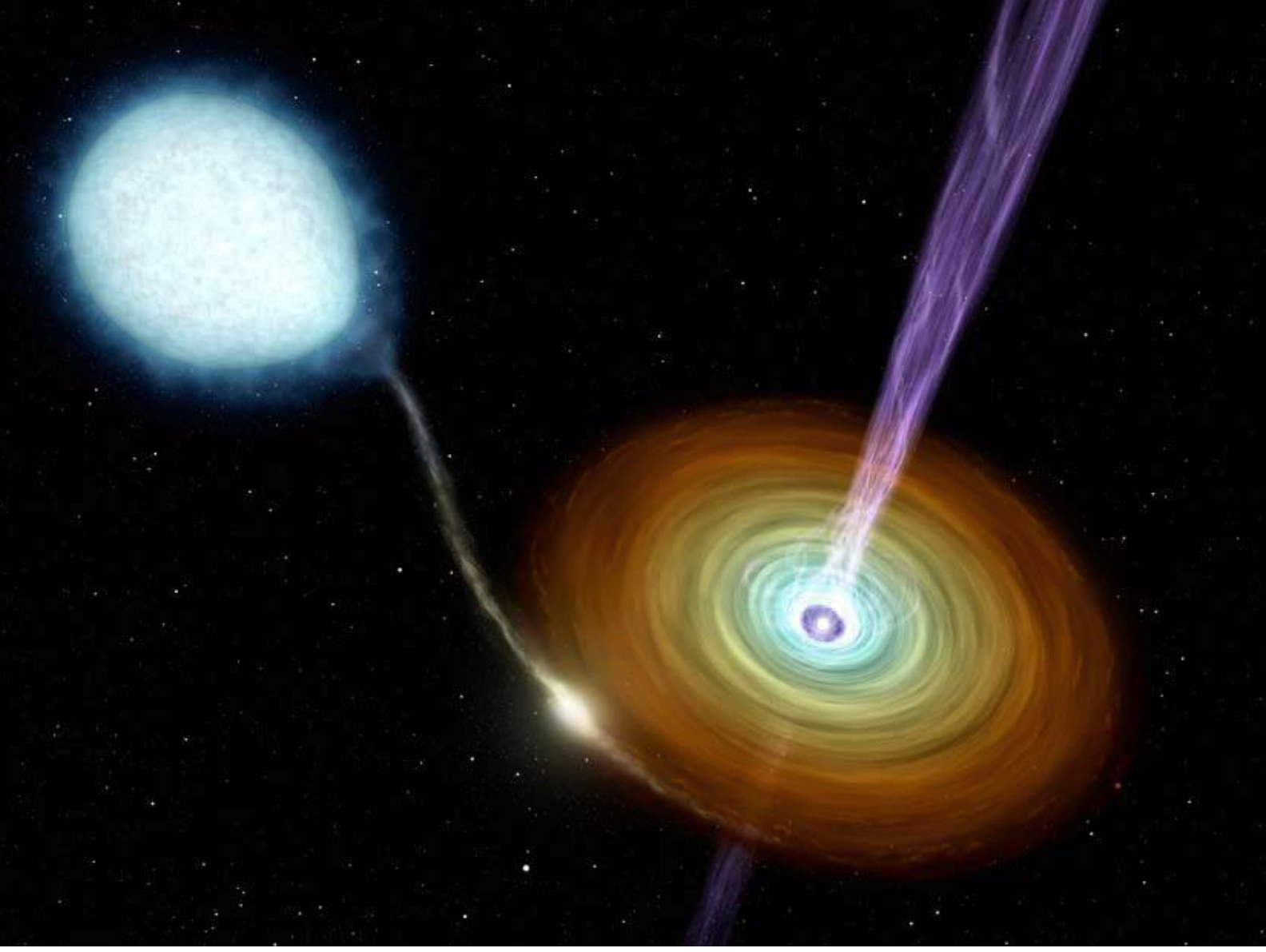
NASA'S CHANDRA X-ray Observatory imaged B1957+20, also known as the Black Widow pulsar. The millisecond neutron star lies 5,000 light-years away in Sagitta. The pulsar's high-energy radiation appears to be evaporating its companion star and ejecting its matter from the system. The two leave a wake as they course through the galaxy. X-RAY: NASA/CXC/ASTRON/B. STEPPERS ET AL., OPTICAL: AAO/J. BLAND-HAWTHORN AND H. JONES

WHAT CONSTITUTES A NEUTRON STAR?

Astronomers believe neutron stars form when a star born with at least 8 solar-masses collapses and explodes as a supernova. Neutron stars are typically about 12 miles (20 kilometers) across but hold the Sun's mass or more.

The collapse, which begins at the star's center, halts as 2.2 trillion pounds (a trillion kilograms) becomes squeezed into a sugar-cube-sized volume — comparable to an atomic nucleus' density. The star's electrons and protons merge to form neutrons, whose pressure prevents further collapse. The outer 0.6 mile (1 km) forms a solid crust despite temperatures of a million Kelvin.

Magnetic fields, upwards of a trillion times the strength of Earth's, are another hallmark of neutron stars. Astronomers call those with especially powerful fields magnetars. — *Francis Reddy*



THE COMPACT OBJECT holds all the cards in the 4U 0614+091 binary, shown in this artist's concept. The neutron star outweighs its companion by 14 times. Observations by the Spitzer Space Telescope reveal narrow, oppositely directed jets blasting from the accreting neutron star. The system lies 10,000 light-years away in Orion. NASA/JPL-CALTECH/R. HURT (SSC)

the expanding wave to work its way around the neutron star, we see a hot spot that spins in and out of view.

Bending light

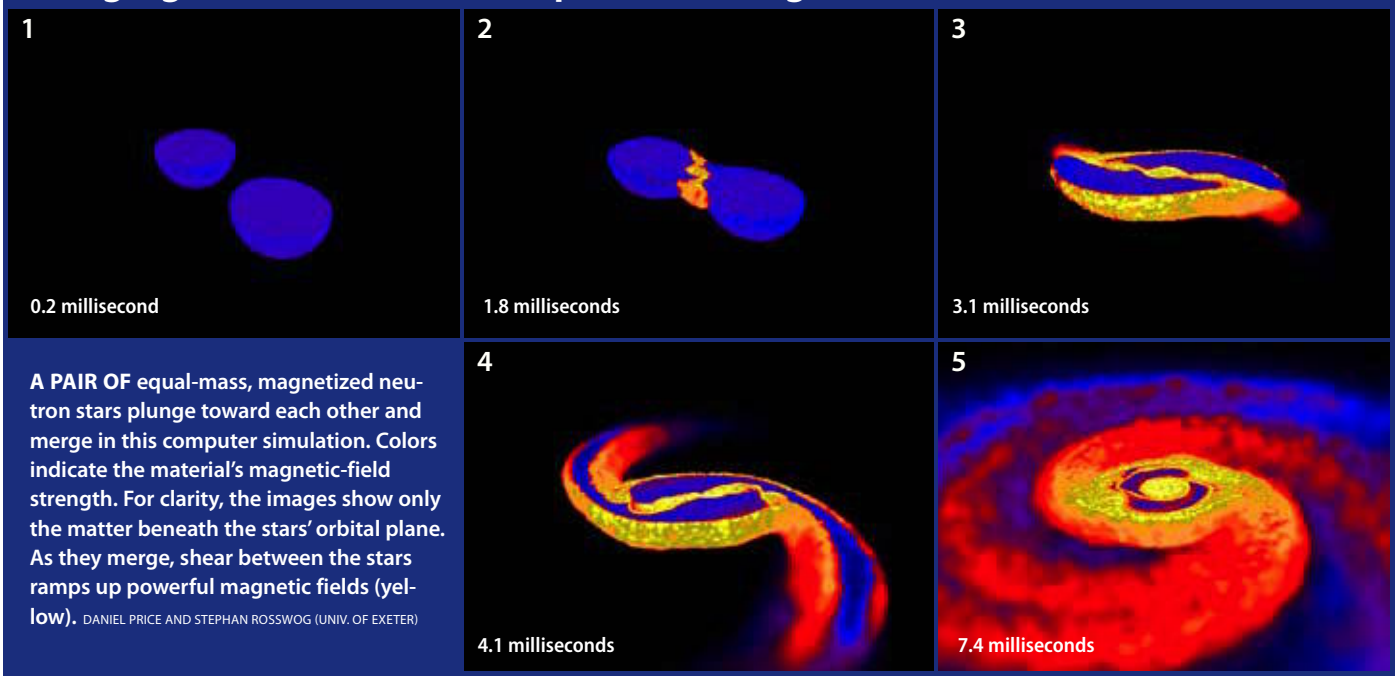
The detailed structure of the pulses — what we call the pulse profile — provides clues to the star's mass and radius. Einstein's theory of general relativity tells us that an object as compact as a neutron star deflects light in its vicinity. In fact, the effect is so strong, it lets astronomers see more than half of the neutron star's surface at any one time. In effect, photons emitted from "behind" the star travel a curved path toward an observer. The more compact the neutron star, the more of its surface we can see. If more of the surface is visible, it weakens any pulse astronomers detect from the star's rotation. In this way, the strength of the pulsation conveys information about how compact the neutron star is.

Other relativistic effects are also at work. A neutron star spinning at 600 Hz has a surface moving at 10 to 20 percent of light-speed. This produces a strong Doppler shift and also beams radiation from the surface. Both effects produce changes in the pulse profile that, in principle, we can observe. They provide ways to measure the neutron star's radius, an extremely difficult quantity to measure accurately.

Astronomers remained puzzled as to why the brightest LMXBs did not show any pulsations in their accretion-powered X-ray emissions. In 1998, Rudy Wijnands at the University of Amsterdam and colleagues found the first accreting millisecond pulsar: SAX J1808.4–3658, with a spin frequency of 401 Hz. Unlike other, non-pulsing LMXBs, this source was transient and unusually faint.

These facts suggested a possible explanation based on how accretion might influence a neutron star's magnetic field. Bright, persistent LMXBs may have had greater recent accretion. This additional accumulation of matter may reduce the magnetic field's influence, making it harder for the neutron star to pulse. Conversely, in weaker, transient systems (like SAX J1808.4–3658), accretion may not have had a chance to suppress their magnetic fields, leaving them strong enough to produce detectable pulsations. The faintness and transient nature of SAX J1808.4–3658 also explained why such objects had been hard to find. As transients, they are not X-ray active for very long, and when they do turn on, they don't get very bright.

Merging neutron stars make powerful magnetic fields



A PAIR OF equal-mass, magnetized neutron stars plunge toward each other and merge in this computer simulation. Colors indicate the material's magnetic-field strength. For clarity, the images show only the matter beneath the stars' orbital plane. As they merge, shear between the stars ramps up powerful magnetic fields (yellow). DANIEL PRICE AND STEPHAN ROSSWOG (UNIV. OF EXETER)

Precise timing of X-ray pulses from the spinning neutron star allows astronomers to measure the system's properties accurately. The neutron star's motion introduces periodic shifts in X-ray-pulse arrival times. In the same way that police radar guns nab speeding motorists, arrival-time shifts let us determine the neutron star's orbit — its period, eccentricity, and size. Such measurements indicate that all of the accreting millisecond pulsars are in circular orbits with periods ranging from 40 minutes to several hours. The size and period of the neutron star's motion also give its companion star's mass. In this case, where we can track the motion of only one component (the neutron star), we can deduce a lower limit to the companion's mass. These studies reveal that all the companions are low-mass stars, or even brown dwarfs, with masses of only 10 to 15 Jupiters.

STUDIES reveal that all the companions are low-mass stars, or even brown dwarfs, with masses of only 10 to 15 Jupiters.

Speed limit

Limits to a neutron star's rotational speed depend on the still-unknown properties of this ultradense matter. The more compressible neutron-star matter is, the faster a star could spin before flinging itself to bits. The most realistic models predict maximum spin rates well above 1,000 Hz.

The record for neutron-star spin was recently broken by the discovery of a 716-Hz binary radio pulsar (PSR J1748–2446ad) by Jason Hessels at McGill University in Montreal and his collaborators. PSR J1748–2446ad still comes in below the limit suggested by the X-ray detections. Perhaps the stars observed today have not had enough time to spin up to near 1,000 Hz, or perhaps the magnetic fields of these neutron stars are sufficient to limit spin-up. It's also possible the emission of gravitational-wave radiation limits how fast neutron stars can spin. If so, gravitational-wave detectors such as the advanced LIGO detector may sense accreting neutron stars.

Understanding the nature of this apparent speed limit will likely require a larger sample of pulsars, and astronomers are continuing the search at X-ray and radio wavelengths.

Einstein's theory gives us one other method to study neutron stars: gravitational redshift. A photon escaping a neutron star gives up some of its energy. The amount lost depends on the star's mass and size. Scientists could measure this loss in the star's atmospheric spectral lines, but astronomers haven't found such features in solitary neutron stars.

These objects likely have much stronger magnetic fields than LMXB neutron stars, and their lack of accretion may explain our inability to detect spectral lines. Strong magnetic fields can smear out the lines. And heavier elements, such as iron, quickly settle out of the neutron star's atmosphere. Without a resupply from accretion, isolated neutron stars may have few line-forming elements available.

New impetus for the search comes from the capabilities of NASA's Chandra and the European Space Agency's XMM-Newton satellites. Future X-ray missions with larger apertures, fast timing, and high-spectral-resolution capabilities, such as NASA's planned Constellation-X fleet, will help provide answers to some of the remaining mysteries surrounding neutron stars. Until then, we'll have to glean what we can by watching these extreme stars interact with normal partners.

ONLINE EXTRA View movies of inspiraling neutron stars at www.astronomy.com/toc.

What makes stars

Sound waves in collapsing stars may produce supernova explosions.

/// BY FRANCIS REDDY

No event in nature surpasses a supernova's raw power. The flood of neutrinos accompanying the explosion of a single massive star releases as much instantaneous power as the rest of the visible universe combined. Such blasts stir interstellar gas and dust, helping new stars to form. More importantly, supernovae disperse most of the elements heavier than carbon — such as the iron in our blood — and create neutron stars and black holes.

After decades of debate, astrophysicists still aren't sure how a star turns into nature's grandest firecracker. Even the most complex computer simulations haven't solved the problem, but they have served up some surprises. For instance, sound waves in a collapsing star's heart could help kick-start a stalled explosion, while a white dwarf's detonation may arise when the star's gravity turns a thermonuclear conflagration back on itself.

The big picture

By the 1930s, it was clear that some stellar flare-ups, called novae, were in a class by themselves. In 1933, astronomers Walter Baade at Mt. Wilson Observatory and Caltech's Fritz Zwicky began referring to the most luminous events as supernovae. They suggested the explosions occurred when a massive star collapsed and created a neutron star. Bear in mind this was more than 3 decades before pulsed radio signals from the Crab Nebula supernova remnant proved that neutron stars exist at all.

In 1941, Mt. Wilson's Rudolph Minkowski proposed supernovae come in two flavors based on the absence (type I) or presence (type II) of strong hydrogen spectral lines at peak brightness. Since then, the observational picture has become more complex as astronomers recognized new subclasses of both types. Nevertheless, astronomers generally agree that two scenarios likely account for most supernovae.

Type Ia occur in all galaxies among an older stellar population. All others — type II, plus types Ib and Ic associated with gamma-ray bursts — prefer galaxies sparkling with star-forming regions, which contain many hot, young, massive stars. Such stars explode when they use up their nuclear fuel and collapse.

Core collapse

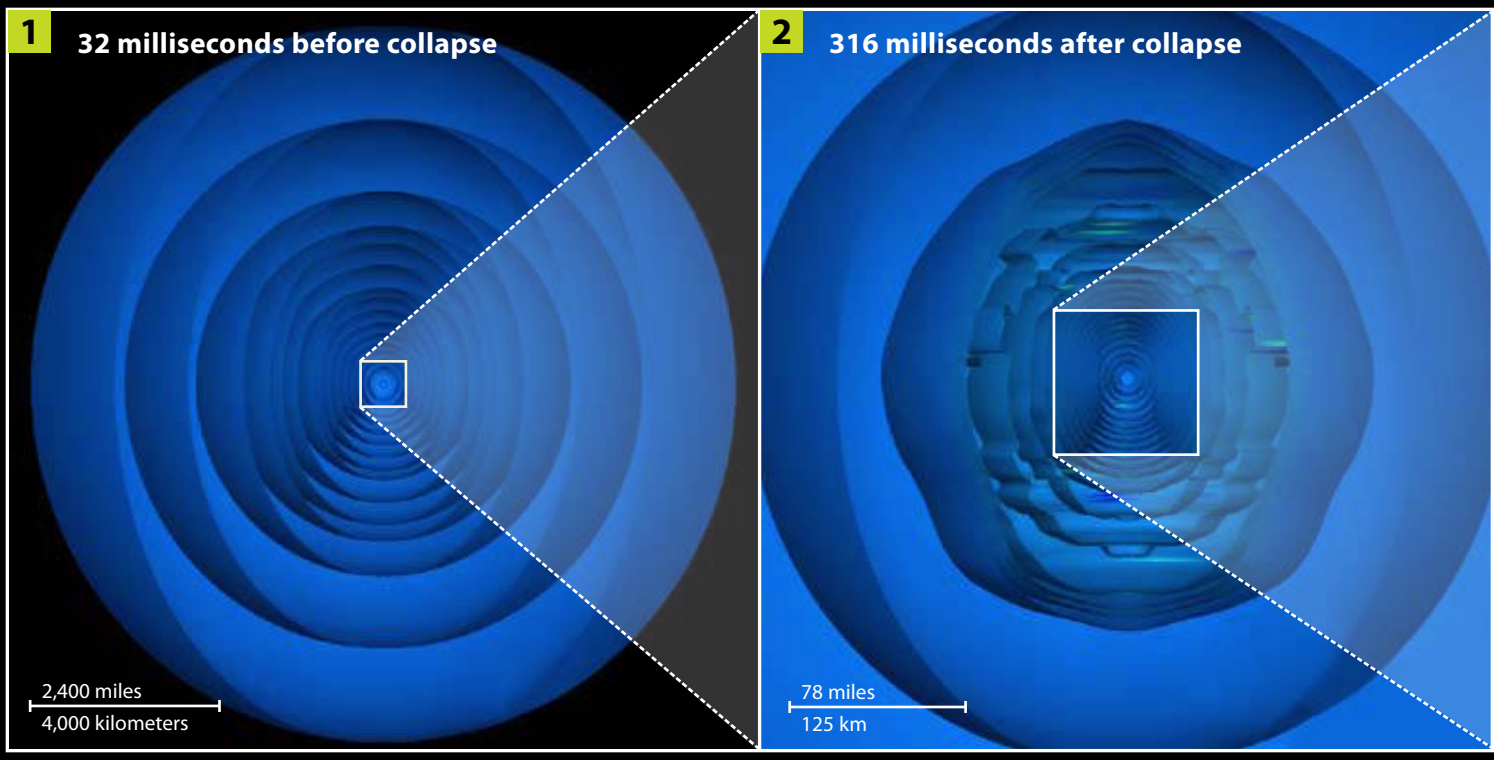
Stars weighing more than about 8 times the Sun's mass burn through their hydrogen fuel quickly, but as a massive star runs low on one fuel, it taps into another. Its core contracts, growing hotter and denser until the previous nuclear reaction's "ash" — helium, at first — undergoes fusion itself. As each fuel runs out, the star's core responds in the same way, running through

Francis Reddy *is an associate editor of* Astronomy.

A SUPERNOVA DETONATES in a spiral galaxy in this illustration. These titanic explosions create and distribute most of the elements, stir up galactic gas and dust, and give astronomers beacons that shine across billions of light-years. ADOLF SCHALLER FOR *ASTRONOMY*

explode?

SINGING SUPERNOVA



A STAR STANDS on the brink of collapse in Adam Burrows' computer simulation. After a few weeks of fusing silicon, the star has created an iron core slightly larger than Earth but more massive than the Sun. This simulation shows the star's iron core as shells of equal density.

THE CORE COLLAPSES, then rebounds as it compresses to densities higher than an atom's nucleus. This launches an outward-moving shock wave that's stalled by infalling gas. Even after ⅓ of a second, neutrino heating fails to get the shock moving again.

a succession of fuels: hydrogen, helium, carbon, neon, oxygen, and silicon.

But this is a game of diminishing returns — each new fuel releases less energy, so the star burns through it even faster. Moreover, once carbon ignites, and the core's temperature approaches a billion degrees, neutrinos form and escape in greater numbers. Formed in many nuclear reactions, neutrinos don't interact easily with other matter and quickly exit the star. To compensate for the energy loss, the core burns its nuclear fuel even faster.

While such a star may take 10 million years or more to run through its "first course" of hydrogen fuel, it consumes its helium in 2 million years, and its carbon in just 2,000 years. The last phase, when the core fuses silicon, lasts less than 3 weeks.

As silicon fusion ends, an Earth-sized iron-nickel core about 1.5 times the Sun's mass resides in the star's center. But iron-group elements have nature's most tightly bound nuclei, so the core can't resort to its old trick — fusing iron actually consumes energy. Neutrinos stream from the core, where the central density is so high that electrons — the star's main pressure source — become squeezed into nuclei, where they transform some protons into neutrons. Both processes remove pressure that supports the star. With pressure losses mounting and no new energy source to tap, the star's battle with gravity is over.

The iron core collapses at about ¼ lightspeed. In half a second or less, it transforms from an Earth-sized stellar core to a hot, dense, proto-neutron star just 19 miles (30 kilometers) across. When the central density reaches about twice that of an atomic nucleus, the core stiffens and rebounds thanks to a repulsive component in the strong nuclear force. This core "bounce" acts like a spherical piston that drives into the star's infalling gas.

"It was hoped this piston would generate a shock that would be the supernova in its infancy," says Adam Burrows, who models supernovae at the University of Arizona. "That was sweet, and it made some sort of sense, but it doesn't work." As the shock moves out, it radiates lots of neutrinos, which saps its energy. "In addition, it's trying to overcome all that stuff that's still falling in, and it fails."

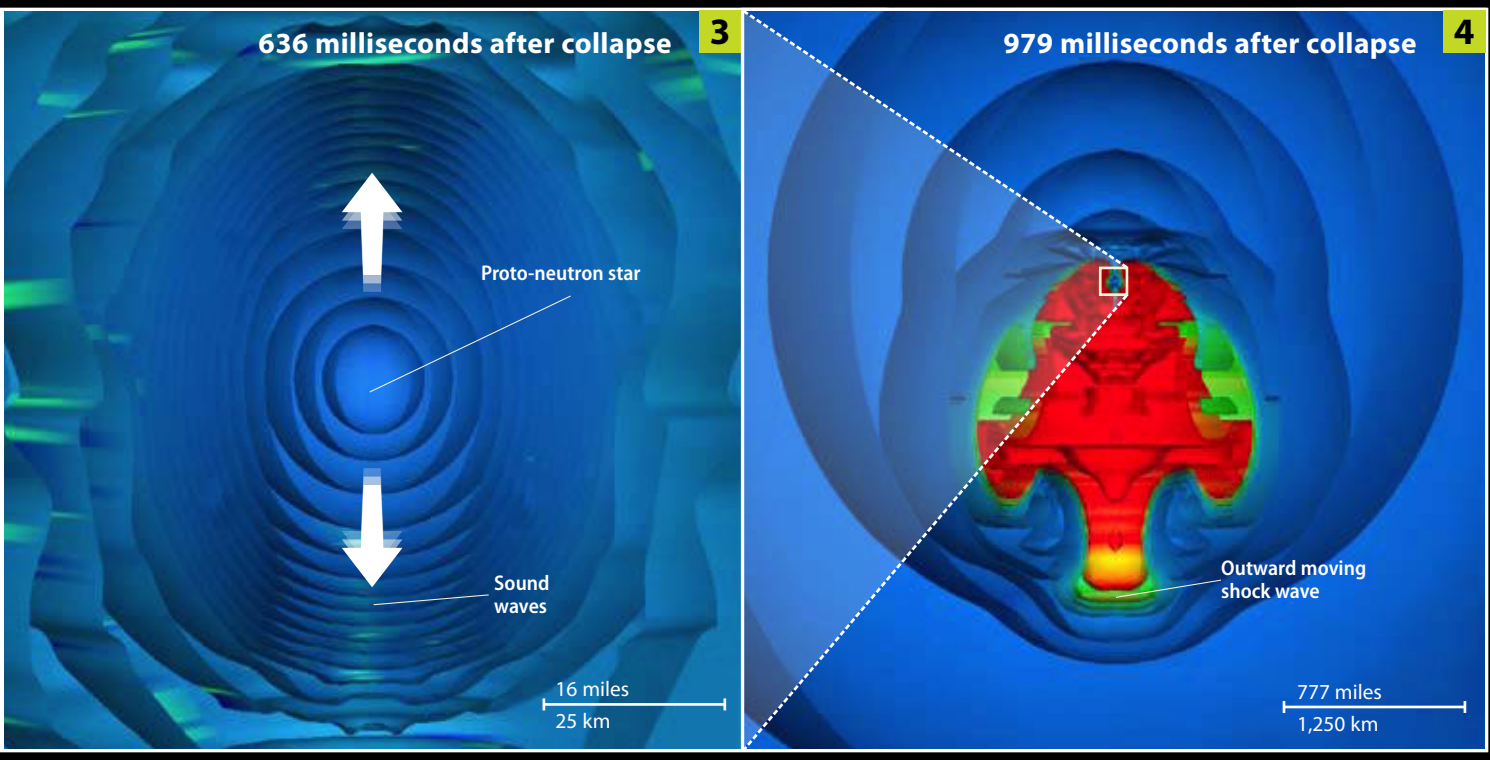
The shock stalls a few milliseconds after it starts and simply sits there, heating the infalling gas. If nothing changed during the next second, the nascent neutron star would accrete a few tenths of a solar-mass of matter and become crushed into a black hole. No supernova.

The pause that refreshes

The central mystery of core-collapse supernovae is how this situation ever can turn itself around. "What people had suggested was, you wait a while, and neutrinos eventually heat up the material behind the shock enough that you re-launch an explosion," says Burrows. He calls this "the pause that refreshes."

The number of neutrinos departing the core makes up for the low odds that a single neutrino will interact with the star's matter as it leaves. The action pauses just a few hundred milliseconds, but, says Burrows, "That's a long time in this game, because things happen fast."

In early computer models, which assumed the collapsing star was spherically symmetric, even this process didn't work. Such 1-D calculations gave way to more demanding 2-D models, which assume symmetry around the star's spin axis. They revealed fluid instabilities and turbulence that promised to aid the stalled shock.



ADAM BURROWS (UNIVERSITY OF ARIZONA)

TURBULENT GAS falling onto the proto-neutron star causes it to oscillate about 300 times a second, a frequency that corresponds to the musical note F above middle C. Sound waves expand into the gas, and force the shock to wobble.

SOUND WAVES deposit nearly all their energy into the gas. This forces infalling streams to one side of the neutron star and clears a path on the other. Acoustic energy revitalizes the shock wave, which now moves outward. A supernova is born.

"For a while, that was the prevailing view," Burrows explains. "But with the best neutrino physics, it doesn't look like this works in 2-D." Will new effects in 3-D simulations help neutrinos deposit energy more efficiently? "That's still the hope," he says.

In 2005, Burrows and his colleagues discovered a potentially important alternative energy source in collapsing stars: sound waves. In the team's 2-D model, the stalled shock starts to wobble top-to-bottom along the star's spin axis. "People hadn't seen this before because they had waited for maybe 200 milliseconds after bounce," Burrows explains. "And the shock just went up, it stalled, and it went back down." Nothing more happened, so supernova modelers ended their expensive computer runs.

As matter streams onto the proto-neutron star, turbulence around the core sets it oscillating at around 300 hertz — musically, about F above middle C. Acoustic waves radiate back into the collapsing envelope. While the energy from neutrinos is far greater, only a fraction of it becomes deposited in the stalled shock, whereas matter absorbs sound almost completely.

ARE TYPE IA SUPERNOVAE REALLY ALL ALIKE?

Similarities in the spectra and light outputs of type Ia supernovae outweigh their differences, a fact that makes these explosions our most important beacons in the far universe. Evidence from type Ia supernovae fuels astronomers' ideas about dark energy and the expanding universe's acceleration.

"The peak luminosities and kinetic energies of type Ia supernovae span a range of roughly a factor of 10, so there may well be several different mechanisms at work," says the University of Chicago's Don Lamb.

SN 2003fg is a case in point. Andrew Howell at the University of Toronto led an international team that studied the event, which occurred in a galaxy 4 billion light-years away. In September 2006, the researchers published their conclusion that the explosion's progenitor star was more massive than theory allows a solitary white dwarf to be.

Either SN 2003fg was spinning so fast its rotation supported a mass above the Chandrasekhar limit, or, the group suggests, a pair of orbiting white dwarfs merged. Team member Richard Ellis of Caltech says the find illustrates how much more astronomers need to learn about supernovae to extend current studies.

White-dwarf-merger scenarios are "particularly challenging" for large-scale numerical simulations, says Lamb. No detailed simulations have been completed so far. — *F. R.*

TYPE IA SUPERNOVA 1994D outshines its spiral galaxy, NGC 4526. NASA/ESA/HUBBLE KEY PROJECT/HIGH-Z SUPERNOVA SEARCH TEAM

There's enough acoustic power to blow the star apart half a second after core bounce in Burrows' simulation.

How important this process is remains an open question. It's the accreting material that keeps a lid on the explosion, preventing neutrinos from moving the shock out. "If the neutrino mechanism worked, we would have seen it in our model," Burrows says.

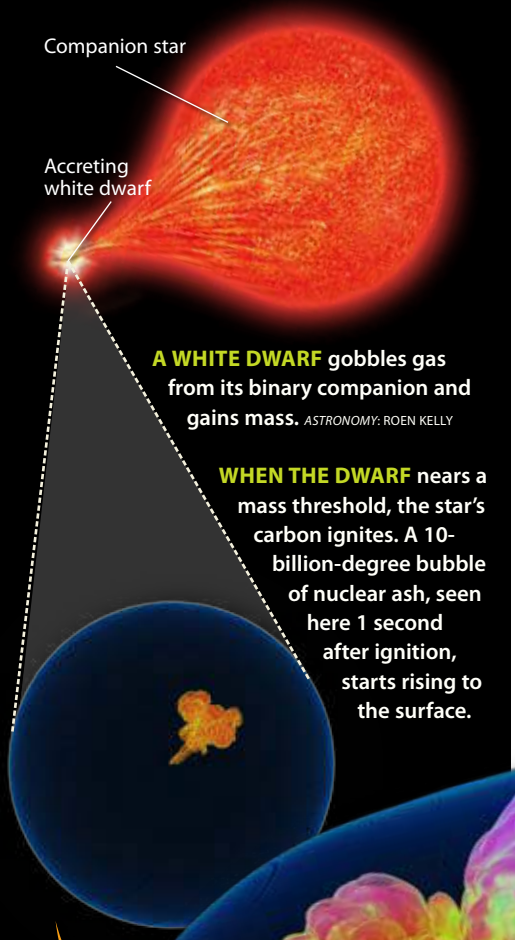
The sound waves push streams of accreting matter to one side of the core while energizing the shock on the opposite side. So, by creating a path of least resistance, sound may help neutrinos revitalize a stalled shock. "It's unproven," he says, "but very interesting." Moreover, the oscillating core could be a prominent source of gravitational radiation.

Shattered dwarfs

Large-scale computer simulations are also providing new insights into how white dwarfs, the end state of low-mass stars, destroy themselves as type Ia supernovae. Brighter and more uniform than core-collapse explosions, type Ia events are important probes of the distant universe. The discoveries of dark energy and cosmic acceleration add urgency to deciphering how they work.

A Sun-like star ends its days as a white dwarf, with the star's carbon-oxygen-rich core crushed to Earth's size. Most shine for billions of years, gradually cooling until they fade into dark stellar cinders. Electron pressure prevents further collapse, but it works only if the dwarf weighs less than 1.44 Suns — the so-called Chandrasekhar limit. Exceed that, and collapse resumes until the dwarf becomes a neutron star.

In 1960, University of Cambridge astronomer Fred Hoyle and Caltech's William Fowler realized a white dwarf near this limit could be a giant thermonuclear bomb. Place a white dwarf in close proximity to a normal star, and the dwarf can gain mass until it nears the 1.44-Sun threshold and explode. The dwarf gobbles up hydrogen gas



A WHITE DWARF gobbles gas from its binary companion and gains mass. *ASTRONOMY*: ROEN KELLY

WHEN THE DWARF nears a mass threshold, the star's carbon ignites. A 10-billion-degree bubble of nuclear ash, seen here 1 second after ignition, starts rising to the surface.

THE BUBBLE BREECHES the dwarf's surface 1.4 seconds after ignition in this simulation. The hot cloud of fusion products isn't moving fast enough to go into orbit. Instead, the dwarf's gravity confines the bubble to the star's surface (blue).

THE EXPANDING BUBBLE hugs the dwarf's surface and plows some of the star's unfused material ahead of it. We view the cloud 1.56 seconds after ignition — the last moment of the 3-D simulation by Calder's team. Following up with 2-D models, the astronomers showed this cloud wraps around the star in less than half a second. The cloud meets itself on the dwarf's opposite side. When it does so, the unfused surface matter the bubble plowed up crashes together and explodes, destroying the star.

TOMASZ PLEWA, ALAN CALDER, DEAN TOWNSLEY, SHIMON ASIDA, TRIDIVESH JENA, FANG PENG, IVO SEITENZAHL, JIM TRURAN, GEORGE JORDAN, CARLO GRAZIANI, JU ZHANG, ALEXEI KHOKHLOV, ANDREY ZHIGLO, ALEXEI POLUDNENKO, BRONSON MESSER, ED BROWN, AND DONALD LAMB (U.S. DEPARTMENT OF ENERGY ADVANCED SIMULATION AND COMPUTING PROGRAM, ALLIANCE FLASH CENTER, AND THE ARGONNE NATIONAL LABORATORY FUTURES LAB)

from its partner at a probable rate of about ⅓₀ of an Earth-mass per year. If it's much slower than this, the dwarf's stellar wind prevents the gas from reaching the surface; if it's any faster, the gas will flash-fuse rather than accumulate.

As a white dwarf tips the scale toward 1.44 Suns, its carbon ignites somewhere inside. Before 2004, no one could figure out how to make a carbon-oxygen star detonate, so theorists first invoked turbulent thermonuclear fusion. These models failed to match the energy and element mix of type Ia blasts. Models that followed a period of turbulent burning with a detonation better matched reality, but theorists simply decided where and when the explosion would occur and inserted it into the simulation. "I sometimes refer to this as the 'Here, a miracle occurs' mechanism," says the University of Chicago's Don Lamb.

For this reason, Wolfgang Hillebrandt and his group at the Max Planck Institute for Astrophysics in Munich, Germany, tried a different tack. They found that models using turbulent burning alone can better match observations, but, to do so, the dwarf's thermonuclear fires must ignite in about 100 different points at once. That's very unlikely. Says Lamb: "We worry one miracle has been replaced by another."

In 2004, a team led by Alan Calder at the University of Chicago including Lamb, stumbled onto a way to blow up a white dwarf. Thanks to the U.S. Department of Energy's computational resources, the team had the hardware to simulate an entire white-dwarf star. After ignition, a narrow front of nuclear flame expanded through the star, leaving behind a 10-billion-degree ash bubble. When this bubble broke through the dwarf's crust, less than 10 percent of the star's mass had been fused — too little to disrupt the dwarf or produce a strong explosion. "It looked like it might be a dud," Lamb recalls.

Then, team member Tomasz Plewa performed additional 2-D simulations to see what happens after the bubble breeches the star's surface. The nuclear ash erupts, moving at around 6.7 million mph (10.8 million km/h), just shy of orbital speed. The hot cloud hugs the dwarf's billion-degree surface and rapidly spreads. As it does so, it plows up cooler, unfused surface matter. The superheated ash-cloud wraps around the white dwarf and meets itself at the point opposite its breakout. The collision compresses all of the unfused surface material, which explodes and rips the star apart.

The model, called "gravitationally confined detonation," is the most complete description of a type Ia supernova to date — and the only one in which a full-scale detonation naturally occurs. "It's a very promising model for most type Ia supernovae," Lamb says. "It was a serendipitous discovery. And it is a perfect example of how large-scale numerical simulations can lead to discoveries of complex, non-linear phenomena that are very difficult to imagine ahead of time," he adds.

Seventy-four years after astronomers connected supernovae with stellar deaths, the universe's most powerful explosions still tax astrophysicists. Yet, even the most complete simulations don't yet capture the complex environment of an exploding star. Modelers are beginning to probe how neutrino emission, magnetic fields, and rotation affect the picture. Observers watch and catalog new events, using them both as cosmic yardsticks and to find holes in current understanding. And new facilities designed to capture neutrinos and gravitational waves — signals that directly escape an exploding star's core — one day soon may give us a glimpse of a supernova's chaotic heart.

ONLINE EXTRA See movies of supernova simulations at www.astronomy.com/toc.

BY MARTIN RATCLIFFE AND ALISTER LING

MARCH 07

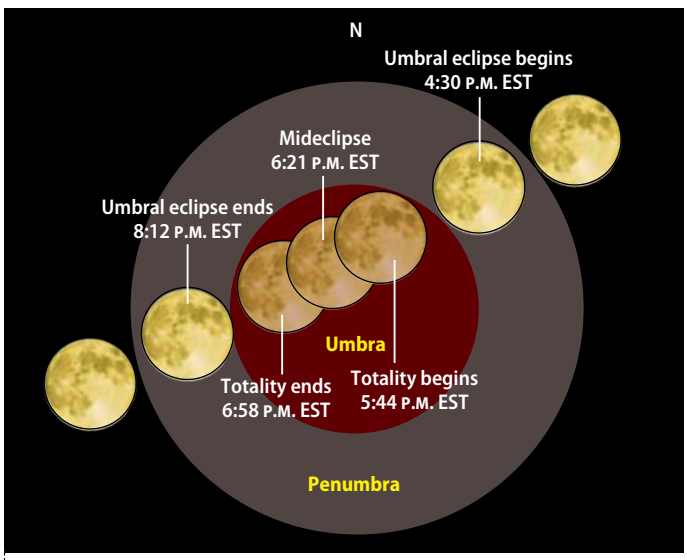
A lunar eclipse takes center stage

A TOTALLY ECLIPSED MOON takes on different shades depending on conditions in Earth's atmosphere. Colors range from coppery orange to dull brown. MARTIN BERNER

North Americans haven't seen a total eclipse of the Moon since October 2004. This month, on March 3, the wait is over. The giant planets, Jupiter and Saturn, are also on display at various times during the night: Saturn in the early evening and Jupiter after midnight. Yet the evening's first glowing attraction is Venus, which is prominent in the western sky. Start following the subtle changes of its sunlit disk this month. As spring turns into summer, Venus' phase will morph at a faster pace.

44 Total eclipse of the Moon
49 Moon meets Venus
49 Explore lunar crater Bianchini
50 When to view the planets
50 A tale of two comets
51 Asteroid 23 Thalia
51 Find Saturn's moon Titan

Visible to the naked eye
Visible with binoculars
Visible with a telescope



THE MOON SLIPS INTO EARTH'S SHADOW March 3 in the first total lunar eclipse since 2004. Observers on North America's East Coast will enjoy 75 minutes of darkened Moon. *ASTRONOMY:* ROEN KELLY

The Moon courses through Earth's shadow

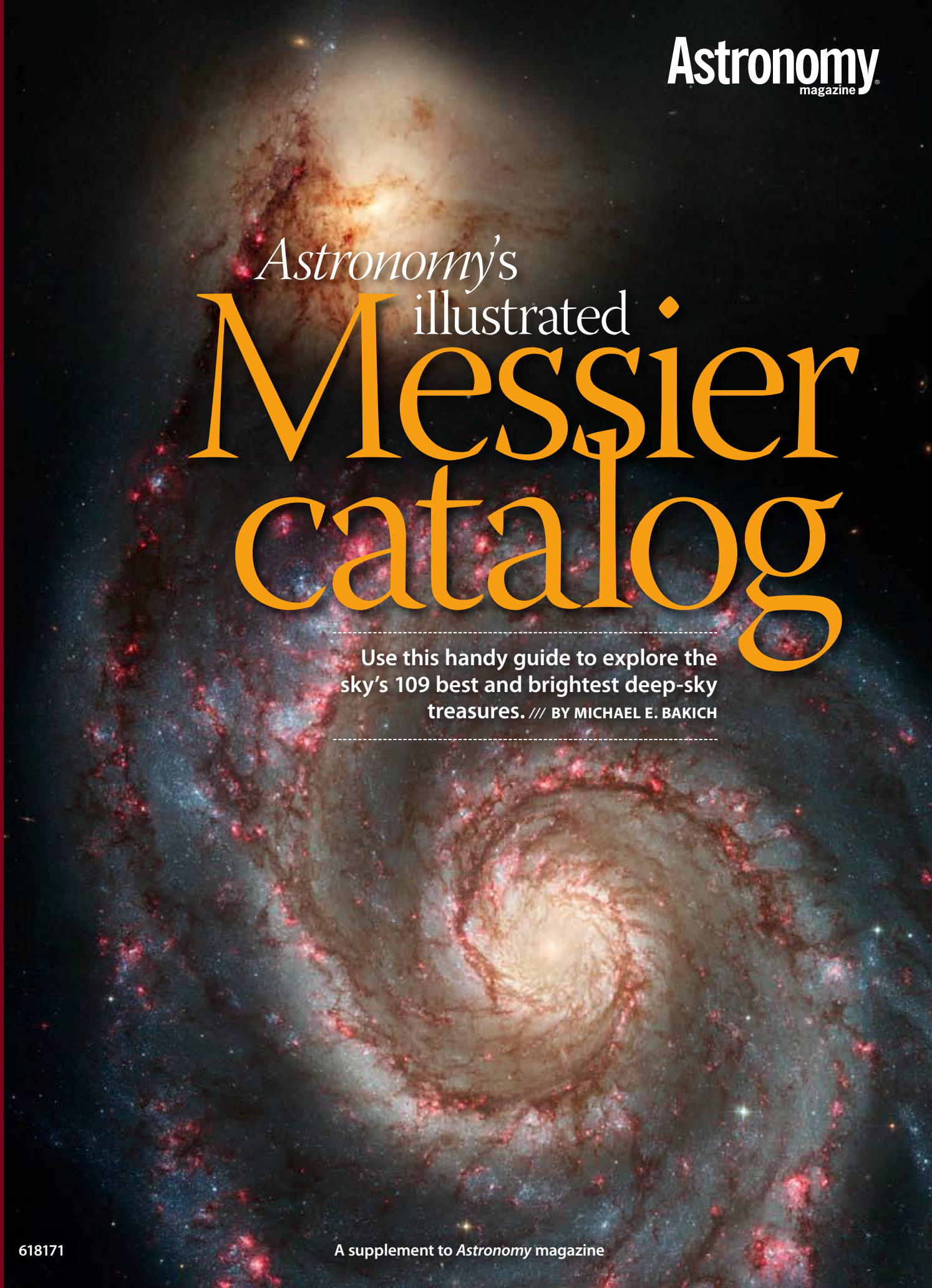
On March 3, the Full Moon rises already eclipsed for East Coast observers, and later stages are visible progressively farther west. When the Moon completes its entry into Earth's shadow, at 5:44 P.M. EST, the **total lunar eclipse** begins.

What color will the Moon turn at mideclipse? Orange? Crimson? Brick red? Brown? Lunar eclipses exhibit a range of shades because sunlight passing through Earth's atmosphere becomes scattered and reddened. It's this dim glow that fills Earth's shadow and lights the eclipsed Moon.

At sunset, minutes before totality, observers from New York eastward will see the Moon sporting a thin, bright rim on its top edge. Totality has already begun when the Moon crests the eastern horizon for spectators to the west. On any other day, when the Sun sets, it often turns orange, or even red, thanks to the longer path its light must take close to the

— *continued on page 49*

Astronomy magazine



Astronomy's illustrated Messier catalog

Use this handy guide to explore the sky's 109 best and brightest deep-sky treasures. /// BY MICHAEL E. BAKICH

618171

A supplement to *Astronomy* magazine

Charles Messier (1730–1817) was a French comet-hunter. Between 1760 and 1798, he discovered 13 comets. But he occasionally encountered celestial objects that looked like comets because they appeared fuzzy in his small telescope. These objects didn't move against the starry background, however.

Astronomers of the day called these objects nebulae, after the Latin word for "cloud," but the word has a more specific meaning today. The catalog Messier eventually compiled contains open and globular star clusters, galaxies, and both bright and planetary nebulae.

Charles Messier (1730–1817)

Messier discovered the first of his non-moving objects in Taurus August 28, 1758. This object became his first catalog entry — M1. Messier published three versions of this catalog. The first, in 1769, contained 45 objects. Messier published the second, with 68 objects, in 1780. The third, which listed 103 objects, appeared the next year. Later discoveries by Messier and others brought the final tally of objects to 109.

Messier marathons

Messier's objects are not distributed evenly across the sky, so a window exists in March when observers can see all 109 objects in a single night — this observing feat is called a Messier marathon. Messier marathons have been popular with astronomy clubs since the early 1970s. One of the first mentions of the Messier marathon was by California comet-hunter Don Machholz in the Forum section of the March 1980 *Astronomy*.

Tom Polakis of Arizona City, Arizona, calculated the Messier marathon window of opportunity. The window opens when globular cluster M30 is high enough to see in a dark morning sky. Working with the premise that the object has to be at an altitude of 2° to be seen, Polakis calculated the Sun's altitude at that time and its distance from M30. Early in the evening, the limiting object is spiral galaxy M74.

Polakis' numbers are for 33° north latitude, and they get more favorable as you observe farther south, particularly for M30. The season begins March 17. Using the same criterion for the evening view of M74, the season ends April 3.

Can you see them all?

Many observers have viewed all 109 objects in one night. You need a 3-inch or larger telescope and a clear, dark site. Some observers challenge themselves by using binoculars.

Don't rush. You'll have plenty of time to observe all these objects, even the close-knit Virgo galaxies. In fact, there's even a period — around midnight local time — when you can get some sleep. Whether you take advantage of this or not depends on how much fun you're having with your fellow observers.

Michael E. Bakich *is a senior editor of* Astronomy.

TEN TIPS FOR A MESSIER MARATHON

1. Connect with a local astronomy club. If you do this, the rest of these tips probably will be taken care of by others. Don't be shy about asking more experienced observers for help.
2. Choose a dark site with a low horizon. Remember, two of the objects (M74 and M30) will be low when you observe them.
3. Bring a good star atlas, and know its layout before the marathon. Some observers make a separate page and note which Messier objects appear on each map.
4. Review your observing plan before you head out. For an online planning guide, visit www.astronomy.com/Messier.
5. Bring warm clothes, and dress in layers. It may be spring, but you won't be running a marathon. Instead, you'll be standing, sitting, looking, and talking. You will get cold.
6. Bring and use only a red flashlight, preferably a dimmable one. White light — in fact, bright light of any color — harms observers' night vision.
7. Bring a comfortable observing chair, and use it. You'll be out all night, and standing that long on hard ground isn't an option.
8. Keep a log of the Messier objects you observe. Your log can have lots of details: time, telescope, eyepiece/magnification, even sketches. Alternately, you can use a simple checklist.
9. Don't get frustrated when searching for galaxies in Virgo. It's not that you won't be able to see them; rather, you'll see more than just the "M" objects. Take your time, and check your star chart often.
10. Check your telescope and accessories at home beforehand. Even if this means setting up in your living room, you'll solve problems more easily at home than outside in the dark. — *M. E. B.*

M2

M3

M4

M5

M6

M7

M9

M10

M11

M12

M15

M16

M17

M18

M19

M22

M23

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M25

M26

M28

M29

M30

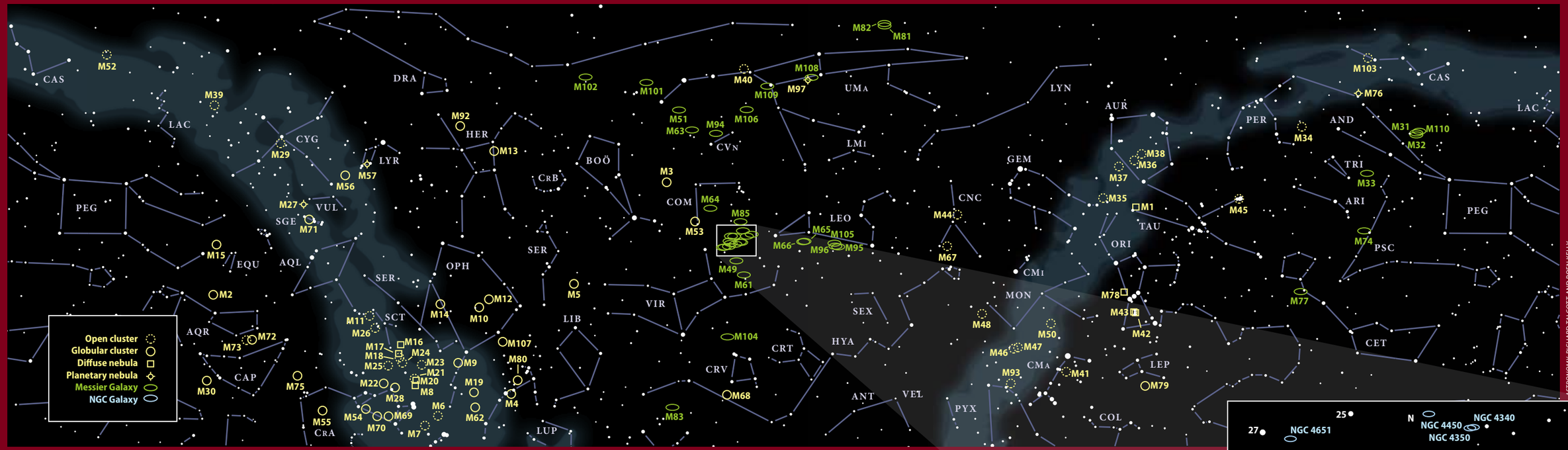
M31

M33

M34

M35

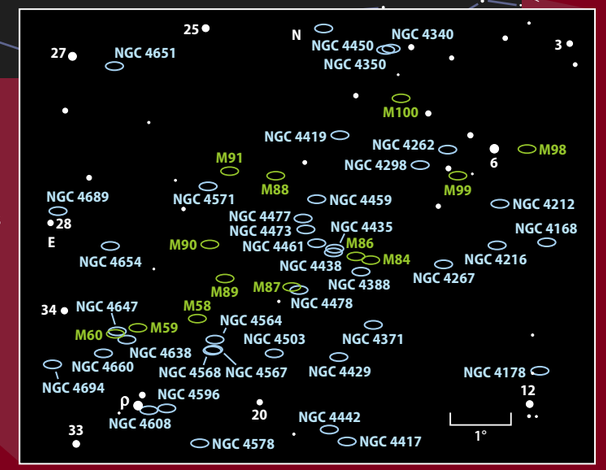
M36



MESSIER NUMBER	OTHER DESIGNATION	RIGHT ASCENSION	DECLINATION	CONSTELLATION	TYPE	MAGNITUDE	SIZE
M1	NGC 1952	5h35m	22°01'	Taurus	Supernova remnant	8.0	6' by 4'
M2	NGC 7089	21h33m	–0°49'	Aquarius	Globular cluster	6.3	16'
M3	NGC 5272	13h42m	28°23'	Canes Venatici	Globular cluster	5.9	18'
M4	NGC 6121	16h24m	–26°31'	Scorpius	Globular cluster	5.4	36'
M5	NGC 5904	15h19m	2°05'	Serpens	Globular cluster	5.7	23'
M6	NGC 6405	17h40m	–32°16'	Scorpius	Open cluster	4.2	25'
M7	NGC 6475	17h54m	–34°47'	Scorpius	Open cluster	2.8	75'
M8	NGC 6523	18h04m	–24°23'	Sagittarius	Nebula	6.0	90' by 40'
M9	NGC 6333	17h19m	–18°31'	Ophiuchus	Globular cluster	7.8	12'
M10	NGC 6254	16h57m	–4°06'	Ophiuchus	Globular cluster	6.6	20'
M11	NGC 6705	18h51m	–6°16'	Scutum	Open cluster	5.3	14'
M12	NGC 6218	16h47m	–1°57'	Ophiuchus	Globular cluster	6.8	16'
M13	NGC 6205	16h42m	36°28'	Hercules	Globular cluster	5.3	20'
M14	NGC 6402	17h38m	–3°15'	Ophiuchus	Globular cluster	7.6	11'
M15	NGC 7078	21h30m	12°10'	Pegasus	Globular cluster	6.0	18'
M16	NGC 6611	18h19m	–13°47'	Serpens	Open cluster	6.0	7'
M17	NGC 6618	18h21m	–16°11'	Sagittarius	Nebula	7.0	11'
M18	NGC 6613	18h20m	–17°08'	Sagittarius	Open cluster	6.9	9'
M19	NGC 6273	17h03m	–26°16'	Ophiuchus	Globular cluster	6.8	17'
M20	NGC 6514	18h03m	–23°02'	Sagittarius	Nebula	9.0	28'
M21	NGC 6531	18h05m	–22°30'	Sagittarius	Open cluster	5.9	13'
M22	NGC 6656	18h36m	–23°54'	Sagittarius	Globular cluster	5.2	32'
M23	NGC 6494	17h57m	–19°01'	Sagittarius	Open cluster	5.5	27'
M24	NGC 6603	18h17m	–18°29'	Sagittarius	Star cloud	2.5	90'
M25	IC 4725	18h32m	–19°15'	Sagittarius	Open cluster	4.6	32'
M26	NGC 6694	18h45m	–9°24'	Scutum	Open cluster	8.0	15'
M27	NGC 6853	20h00m	22°43'	Vulpecula	Planetary nebula	7.3	8' by 5.7'
M28	NGC 6626	18h25m	–24°52'	Sagittarius	Globular cluster	6.9	11'
M29	NGC 6913	20h24m	38°32'	Cygnus	Open cluster	6.6	7'
M30	NGC 7099	21h40m	–23°11'	Capricornus	Globular cluster	6.9	12'
M31	NGC 224	0h43m	41°16'	Andromeda	Galaxy	3.4	178' by 63'
M32	NGC 221	0h43m	40°52'	Andromeda	Galaxy	8.2	8' by 6
M33	NGC 598	1h34m	30°39'	Triangulum	Galaxy	5.7	73' by 45'
M34	NGC 1039	2h42m	42°47'	Perseus	Open cluster	5.2	35'
M35	NGC 2168	6h09m	24°20'	Gemini	Open cluster	5.1	28'
M36	NGC 1960	5h36m	34°08'	Auriga	Open cluster	6.0	12'
M37	NGC 2099	5h52m	32°33'	Auriga	Open cluster	5.6	24'
M38	NGC 1922	5h28m	35°50'	Auriga	Open cluster	6.4	21'
M39	NGC 7092	21h32m	48°26'	Cygnus	Open cluster	4.6	32'
M40	Winnecke 4	12h22m	58°05'	Ursa Major	Double star	9.0/9.6	0.8'
M41	NGC 2287	6h46m	–20°44'	Canis Major	Open cluster	4.5	38'
M42	NGC 1976	5h35m	–5°27'	Orion	Nebula	3.7	85' by 60'
M43	NGC 1982	5h36m	–5°16'	Orion	Nebula	6.8	20' by 15'
M44	NGC 2632	8h40m	19°59'	Cancer	Open cluster	3.1	95'
M45	The Pleiades	3h47m	24°07'	Taurus	Open cluster	1.5	110'
M46	NGC 2437	7h42m	–14°49'	Puppis	Open cluster	6.1	27'
M47	NGC 2422	7h37m	–14°30'	Puppis	Open cluster	4.4	30'
M48	NGC 2548	8h14m	–5°48'	Hydra	Open cluster	5.8	54'
M49	NGC 4472	12h30m	8°00'	Virgo	Galaxy	8.4	9' by 7.5'
M50	NGC 2323	7h03m	–8°20'	Monoceros	Open cluster	5.9	16'
M51	NGC 5194	13h30m	47°12'	Canes Venatici	Galaxy	8.4	11' by 7'
M52	NGC 7654	23h24m	61°35'	Cassiopeia	Open cluster	6.9	13'
M53	NGC 5024	13h13m	18°10'	Coma Berenices	Globular cluster	7.7	13'
M54	NGC 6715	18h55m	–30°29'	Sagittarius	Globular cluster	7.2	12'
M55	NGC 6809	19h40m	–30°58'	Sagittarius	Globular cluster	6.3	19'
M56	NGC 6779	19h17m	30°11'	Lyra	Globular cluster	8.4	8.8'
M57	NGC 6720	18h54m	33°02'	Lyra	Planetary nebula	8.8	1.4' by 1'
M58	NGC 4579	12h38m	11°49'	Virgo	Galaxy	9.6	5.5' by 4.5'
M59	NGC 4621	12h42m	11°39'	Virgo	Galaxy	9.6	5' by 3.5'
M60	NGC 4649	12h44m	11°33'	Virgo	Galaxy	8.8	7' by 6'
M61	NGC 4303	12h22m	4°28'	Virgo	Galaxy	9.6	6' by 5.5'
M62	NGC 6266	17h01m	–30°07'	Ophiuchus	Globular cluster	6.7	15'
M63	NGC 5055	13h16m	42°02'	Canes Venatici	Galaxy	8.6	10' by 6'
M64	NGC 4826	12h57m	21°41'	Coma Berenices	Galaxy	8.5	9.3' by 5.4'
M65	NGC 3623	11h19m	13°05'	Leo	Galaxy	8.8	8' by 1.5'
M66	NGC 3627	11h20m	12°59'	Leo	Galaxy	9.0	8' by 2.5'
M67	NGC 2682	8h50m	11°49'	Cancer	Open cluster	6.0	30'
M68	NGC 4590	12h40m	–26°45'	Hydra	Globular cluster	7.6	11'
M69	NGC 6637	18h31m	–32°21'	Sagittarius	Globular cluster	7.4	9.8'
M70	NGC 6681	18h43m	–32°18'	Sagittarius	Globular cluster	7.8	8'
M71	NGC 6838	19h54m	18°47'	Sagitta	Globular cluster	8.0	7.2'
M72	NGC 6981	20h54m	–12°32'	Aquarius	Globular cluster	9.2	6.6'
M73	NGC 6994	20h59m	–12°38'	Aquarius	Open cluster	8.9	2.8'
M74	NGC 628	1h37m	15°47'	Pisces	Galaxy	8.5	10.2' by 9.5'
M75	NGC 6864	20h06m	–21°55'	Sagittarius	Globular cluster	8.6	6.8'
M76	NGC 650	1h42m	51°34'	Perseus	Planetary nebula	10.1	2.7' by 1.8'
M77	NGC 1068	2h43m	–0°01'	Cetus	Galaxy	8.9	7' by 6'
M78	NGC 2068	5h47m	0°03'	Orion	Nebula	8.0	8' by 6'
M79	NGC 1904	5h25m	–24°33'	Lepus	Globular cluster	7.7	9.6'
M80	NGC 6093	16h17m	–22°59'	Scorpius	Globular cluster	7.3	10'
M81	NGC 3031	9h56m	69°04'	Ursa Major	Galaxy	6.9	21' by 10'
M82	NGC 3034	9h56m	69°41'	Ursa Major	Galaxy	8.4	9' by 4'
M83	NGC 5236	13h37m	–29°52'	Hydra	Galaxy	7.5	11' by 10'
M84	NGC 4374	12h25m	12°53'	Virgo	Galaxy	9.1	5'
M85	NGC 4382	12h25m	18°11'	Coma Berenices	Galaxy	9.1	7.1' by 5.2'
M86	NGC 4406	12h26m	12°57'	Virgo	Galaxy	8.9	7.5' by 5.5'
M87	NGC 4486	12h31m	12°24'	Virgo	Galaxy	8.6	7'
M88	NGC 4501	12h32m	14°25'	Coma Berenices	Galaxy	9.6	7' by 4'

▲ MESSIER objects lie all over the northern sky. We've set this chart for mid-March to help you locate these 109 visual treats during a Messier marathon.

▶ IDENTIFYING the Messier objects in Virgo and Coma Berenices requires patience. Remember, Messier's galaxies here are bright.



MESSIER NUMBER	OTHER DESIGNATION	RIGHT ASCENSION	DECLINATION	CONSTELLATION	TYPE	MAGNITUDE	SIZE
M89	NGC 4552	12h36m	12°33'	Virgo	Galaxy	9.7	4'
M90	NGC 4569	12h37m	13°10'	Virgo	Galaxy	9.5	9.5' by 4.5'
M91	NGC 4548	12h35m	14°30'	Coma Berenices	Galaxy	10.1	5.4' by 4.4'
M92	NGC 6341	17h17m	43°08'	Hercules	Globular cluster	6.5	14'
M93	NGC 2447	7h45m	–23°52'	Puppis	Open cluster	6.2	22'
M94	NGC 4736	12h51m	41°07'	Canes Venatici	Galaxy	8.2	7' by 3'
M95	NGC 3351	10h44m	11°42'	Leo	Galaxy	9.7	4.4' by 3.3'
M96	NGC 3368	10h47m	11°49'	Leo	Galaxy	9.2	6' by 4'
M97	NGC 3587	11h15m	55°01'	Ursa Major	Planetary nebula	9.9	3.4' by 3.3'
M98	NGC 4192	12h14m	14°54'	Coma Berenices	Galaxy	10.1	9.5' by 3.2'
M99	NGC 4254	12h19m	14°25'	Coma Berenices	Galaxy	9.9	5.4' by 4.8'
M100	NGC 4321	12h23m	15°49'	Coma Berenices	Galaxy	9.3	7' by 6'
M101	NGC 5457	14h03m	54°21'	Ursa Major	Galaxy	7.9	22'
M102	NGC 5866	15h07m	55°46'	Draco	Galaxy	10.0	5.2' by 2.3'
M103	NGC 581	1h33m	60°42'	Cassiopeia	Open cluster	7.4	6'
M104	NGC 4594	12h40m	–11°37'	Virgo	Galaxy	8.0	9' by 4'
M105	NGC 3379	10h48m	12°35'	Leo	Galaxy	9.3	2'
M106	NGC 4258	12h19m	47°18'	Canes Venatici	Galaxy	8.3	19' by 8'
M107	NGC 6171	16h33m	–13°03'	Ophiuchus	Globular cluster	7.8	13'
M108	NGC 3556	11h12m	55°40'	Ursa Major	Galaxy	10.0	8' by 1'
M109	NGC 3992	11h58m	53°23'	Ursa Major	Galaxy	9.8	7' by 4'

NOTE: Right ascension and declination are 2000.0 coordinates.

ASTRONOMY: RICHARD TALCOTT AND ROBIN KELLY

M37

M38

M39

M40

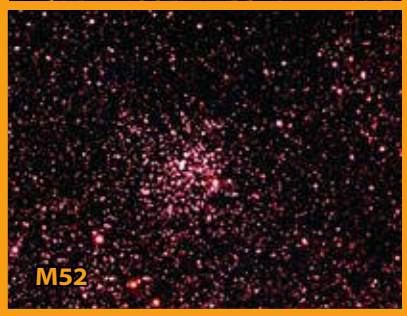
M45

M46

M47

M48

M51


M52

M53

M54

FUN FACTS

Sagittarius contains the most Messier objects (15). Next are Virgo, with 11, and Coma Berenices, with eight.

Fifty-four of the sky's 88 constellations (61 percent) contain no Messier object.

The most northerly Messier object is M82 in Ursa Major, with a declination of 69°41'.

The most southerly Messier object, M7 in Scorpius, has a declination of –34°47'.

The nearest Messier object is M45 in Taurus. It lies approximately 440 light-years away.

The farthest Messier object, M77 in Cetus, lies more than 60 million light-years away.

M45 also ranks as the brightest object in Messier's catalog, shining at magnitude 1.5.

Three objects tie for the faintest Messier object: M76, M91, and M98. Each of these objects glows at magnitude 10.1.

M58

M59

M60

M61

M66

M67

M68

M69

M74

M75

M76

IMAGE CREDITS
COVER: S. BECKWITH (STScI)/HUBBLE HERITAGE TEAM (STScI/AURA)/ESA/NASA; MESSIER PORTRAIT: COURTESY OF OWEN GINGERICH; M1, M14, M15, M17, M33, M61, M74, M76, M79, M87, M94, M96, M98, M99: ADAM BLOCK/NOAO/AURA/NSF; M2, M43: PAT AND CHRIS LEE/ADAM BLOCK/NOAO/AURA/NSF; M3: BILL UMINSKI AND CYNDI KRISTOPEIT/ADAM BLOCK/NOAO/AURA/NSF; M4: GEORGE SEITZ/ADAM BLOCK/NOAO/AURA/NSF; M5: SALLY AND CURT KING/ADAM BLOCK/NOAO/AURA/NSF; M7, M83: ALLAN COOK/ADAM BLOCK/NOAO/AURA/NSF; M8: JACK HARVEY AND TOM DOUGHTERY/ADAM BLOCK/NOAO/AURA/NSF; M6, M9, M18, M19, M21, M23, M25, M26, M28, M29, M30, M39, M40, M41, M47, M48, M49, M50, M54, M59, M60, M68, M69, M70, M71, M72, M73, M84, M85, M86, M89, M93, M105: NOAO/AURA/NSF; M10, M95: MICHAEL AND MICHAEL MCGUIGGAN/ADAM BLOCK/NOAO/AURA/NSF; M11, M37, M46, M55: LEE C. COOMBS; M12: MICHAEL GARIEPY/ADAM BLOCK/NOAO/AURA/NSF; M13, M44: TOM BASH AND JOHN FOX/ADAM BLOCK/NOAO/AURA/NSF; M16, M81, M82, M109: R. JAY GABANY; M20, M31, M51, M57, M101: TONY HALLAS; M22, M92; DOUG MATTHEWS/ADAM BLOCK/NOAO/AURA/NSF; M24: FRED CALVERT/ADAM

TRY A NAKED-EYE MARATHON

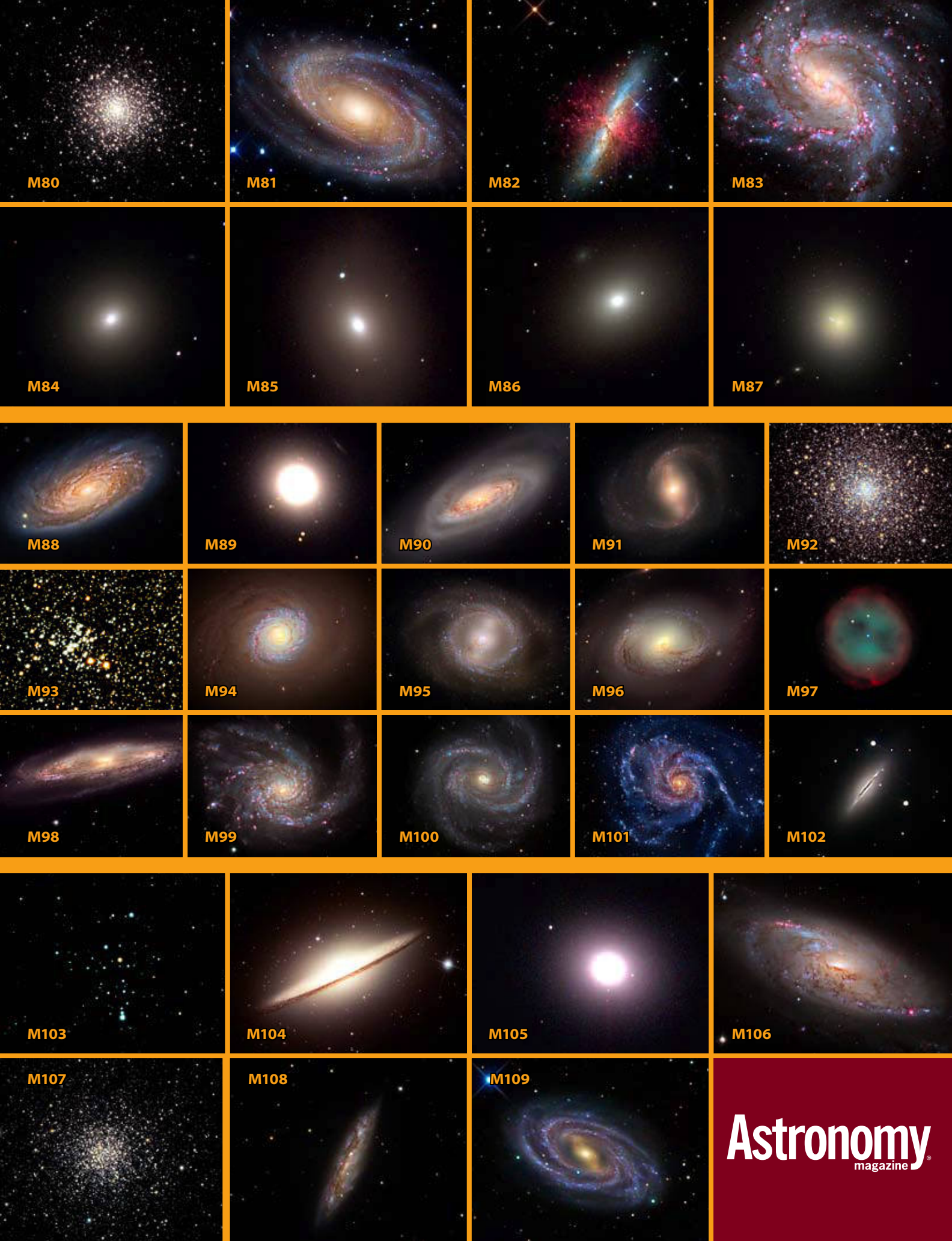
Some observers want an even bigger challenge than a binocular Messier marathon. Here's one: Try to see 20 or more Messier objects with your unaided eyes. A few, like the Pleiades (M45), represent no challenge. Others, like Bode's Galaxy (M81), require a star chart to find.

Brian Skiff of Lowell Observatory in Flagstaff, Arizona, maintains a working list of naked-eye deep-sky objects seen by him or reported to him by reputable observers.

The list includes the following Messier objects: M2, M3, M4, M5, M6, M7, M8, M11, M13, M15, M16, M17, M20, M22, M23, M24, M25, M31, M33, M34, M35, M36, M37, M38, M39, M41, M42, M44, M45, M46, M47, M48, M50, M67, M81, and M93.

Skiff also notes that observers have reported probable naked-eye sightings of M83 and M92. — *M. E. B.*

BLOCK/NOAO/AURA/NSF; M27: JOE AND GAIL METCALF/ADAM BLOCK/NOAO/AURA/NSF; M32: WOLFGANG PROMPER; M34, M36: STEVE CANNISTRA; M35, M67, M103: RUBEN KIER; M38, M52: GEORGE GREANEY; M42: JASON WARE; M45: MARK HANSON AND JEFF HAPEMAN; M53, M56: MICHAEL FULLER; M58: STEVE MANDEL/ADAM BLOCK/NOAO/AURA/NSF; M62: TIM HUNTER; M63,, M66, M88, M108: BOB AND JANICE FERA; M64, M102: CHRIS SCHUR; M65: DOC G. AND DICK GODDARD/ADAM BLOCK/NOAO/AURA/NSF; M75: KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF; M77: FRANCOIS AND SHELLEY PELLETIER/ADAM BLOCK/NOAO/AURA/NSF; M78: DANIEL VERSCHATSE; M80: GENE KATZ/ADAM BLOCK/NOAO/AURA/NSF; M90: PAUL AND DANIEL KOBLAS/ADAM BLOCK/NOAO/AURA/NSF; M91: THOMAS AND GAIL HAYNES/ADAM BLOCK/NOAO/AURA/NSF; M97: GARY WHITE AND VERLENNE MONROE/ADAM BLOCK/NOAO/AURA/NSF; M100: CURT AND SALLY KING/ADAM BLOCK/NOAO/AURA/NSF; M104: MORRIS WADE/ADAM BLOCK/NOAO/AURA/NSF; M106: ADRIAN ZSILAVEC AND MICHELLE QUALLS/ADAM BLOCK/NOAO/AURA/NSF; M107: BRUCE HUGO AND LESLIE GAUL/ADAM BLOCK/NOAO/AURA/NSF


M80
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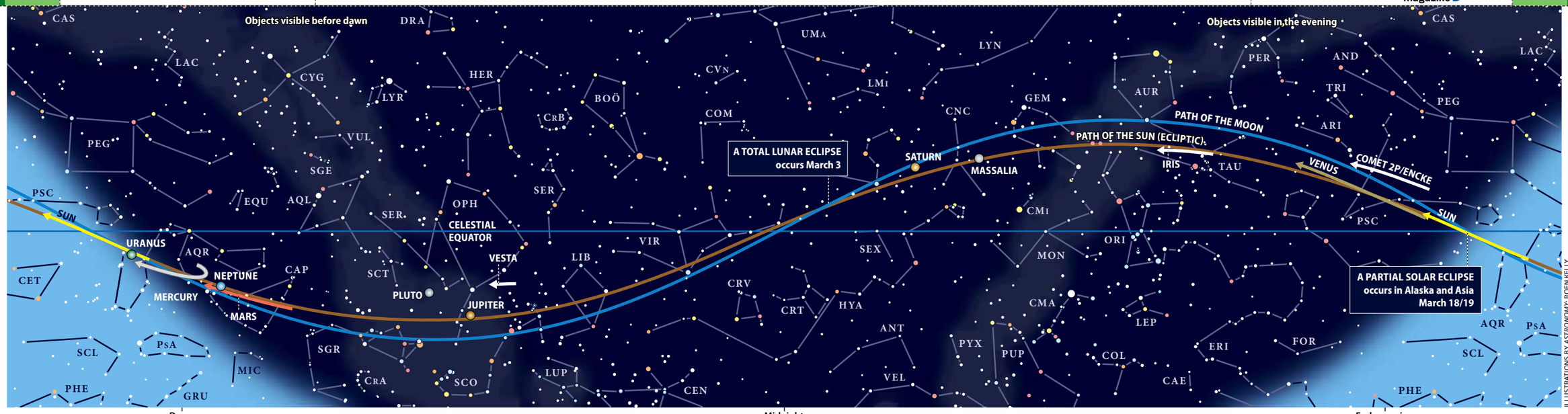
Astronomy
magazine

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

Astronomy magazine



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

[20] [19] [18] [17] [16] [15] [14] [13] [12] [11] [10] [09] [08] [07] [06] [05] [04] [03] [02] [01]

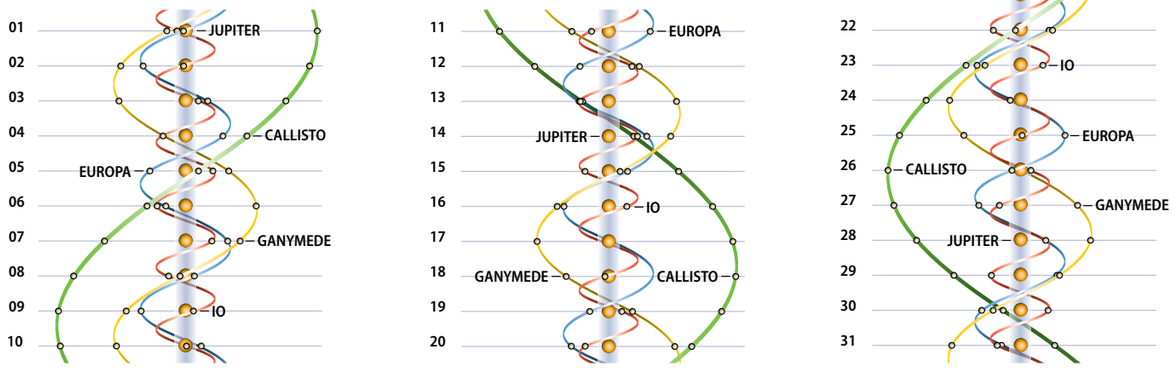
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

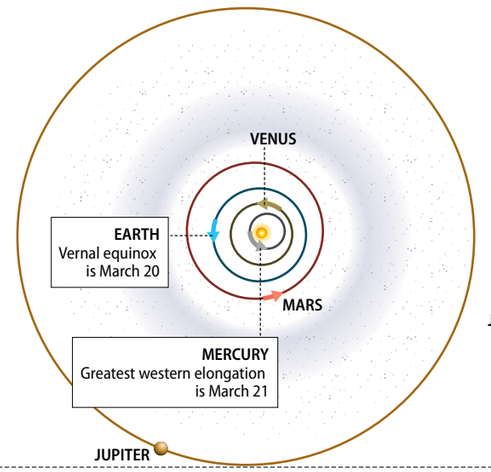
[31] [30] [29] [28] [27] [26] [25] [24] [23] [22] [21] [20] [19] [18]

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	March 15	March 31	March 15	March 15	March 15	March 15	March 15	March 15	March 15
Magnitude	0.4	0.0	−3.9	1.2	−2.1	0.1	5.9	8.0	14.0
Angular size	8.3"	6.5"	12.6"	4.6"	38.2"	19.9"	3.3"	2.2"	0.1"
Illumination	41%	65%	84%	94%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.807	1.039	1.323	2.016	5.166	8.360	21.071	30.875	31.323
Distance (AU) from Sun	0.450	0.463	0.721	1.426	5.345	9.194	20.089	30.049	31.255
Right ascension (2000.0)	21h58.6m	23h03.3m	1h38.0m	21h02.3m	17h12.1m	9h28.1m	23h06.3m	21h32.5m	17h55.0m
Declination (2000.0)	−12°15'	−8°23'	10°06'	−18°01'	−22°16'	16°20'	−6°33'	−14°50'	−16°29'

Jupiter's moons

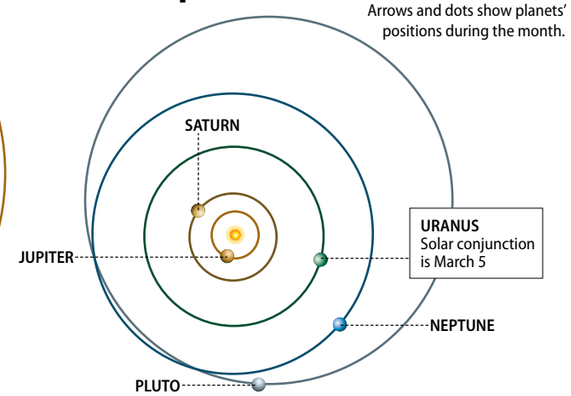
Dots display positions of Galilean satellites at 5 A.M. EDT on date shown. South is at top to match the view through a telescope.





The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth

Astronomy magazine

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SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				[01]	[02]	[03]
[04]	[05]	[06]	[07]	[08]	[09]	[10]
[11]	[12]	[13]	[14]	[15]	[16]	[17]
[18]	[19]	[20]	[21]	[22]	[23]	[24]
[25]	[26]	[27]	[28]	[29]	[30]	[31]

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

01 The Moon passes 1.1° north of Saturn, 9 P.M. EST

02 The Moon passes 1.1° north of Regulus, 4 P.M. EST

03 Full Moon occurs at 6:17 P.M. EST; total lunar eclipse

05 Uranus is in conjunction with the Sun, 11 A.M. EST

06 The Moon is at apogee (252,186 miles from Earth), 10:37 P.M. EST

11 The Moon passes 0.7° south of Antares, 1 A.M. EST

The Moon passes 6° south of Jupiter, 8 P.M. EDT

Last Quarter Moon occurs at 11:54 P.M. EDT

15 The Moon passes 1.9° south of Mars, 9 P.M. EDT

16 The Moon passes 2° south of Neptune, 9 A.M. EDT

16 The Moon passes 1.4° south of Mercury, 11 P.M. EDT

18 New Moon occurs at 10:43 P.M. EDT; partial solar eclipse

19 The Moon is at perigee (222,335 miles from Earth), 2:39 P.M. EDT

20 Vernal equinox occurs at 8:07 P.M. EDT

21 The Moon passes 4° north of Venus, 11 A.M. EDT

Mercury is at greatest western elongation (28°), 10 P.M. EDT

25 Mars passes 1.0° south of Neptune, 3 A.M. EDT

First Quarter Moon occurs at 2:16 P.M. EDT

28 The Moon passes 1.2° north of Saturn, midnight EDT

29 The Moon passes 1.1° north of Regulus, 11 P.M. EDT

ONLINE EXTRA For definitions of terms, visit www.astronomy.com/glossary.

N E W S

PATH OF THE SUN (ECLIPTIC)

HERCULES, DRACO, URSA MINOR, CEPHEUS, CASSIOPEIA, ANDROMEDA, CAMELOPARDALIS, TRIANGULUM, ARIES, BOOTES, CANES VENATICI, URSA MAJOR, LYNX, AURIGA, PERSEUS, CETUS, COMA BERENICES, LEO MINOR, GEMINI, TAURUS, VIRGO, LEO, CANCER, ORION, CANIS MINOR, HYDRA, SEXTANS, CRATER, CORVUS, MONOCEROS, CANIS MAJOR, LEPUS, ERIDANUS, PYXIS, ANTLIA, PUPPIS, VELA, COLUMBA

Polaris, NCP, NGP, Mizar, Alcor, Arcturus, Capella, Algol, Pleiades, Hyades, Aldebaran, Castor, Pollux, Denebola, Regulus, SATURN, Procyon, Betelgeuse, Rigel, Sirius, Adhara, Spica

M13, M92, M51, M82, M81, M36, M38, M37, M35, M1, M44, M66, M65, M64, M104, M33, NGC 869, NGC 884, M42, M47, M41, NGC 2477

Magnitudes

Sirius, 0.0, 1.0, 2.0, 3.0, 4.0, 5.0

Open cluster
Globular cluster
Diffuse nebula
Planetary nebula
Galaxy

Star colors
Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

How to use this map
This map portrays the sky as seen near 35° north latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

— *continued from page 44*
horizon. Coupled with the already orange light from the eclipse, there's a good chance the Moon will appear quite red. Europeans and Africans have the box seats for this one: They're perfectly positioned to watch the entire eclipse.

On the central East Coast, the Moon rises about 5:45 P.M. EST (Eastern Standard Time). In Boston, it rises 15 minutes earlier, and in Miami, at 6:20 P.M., shortly before totality ends. Observers in the Midwest will see the late stages of totality, which ends at 5:58 P.M. CST. The Moon will hug the horizon then, allowing photography of foreground objects as the eclipse progresses.

The end of totality occurs just as the Moon rises for observers along a line from Minnesota, Iowa, Missouri, Arkansas, Mississippi, and south to the Louisiana coast near New Orleans. West of this line, only the final, partial phases of eclipse are visible.

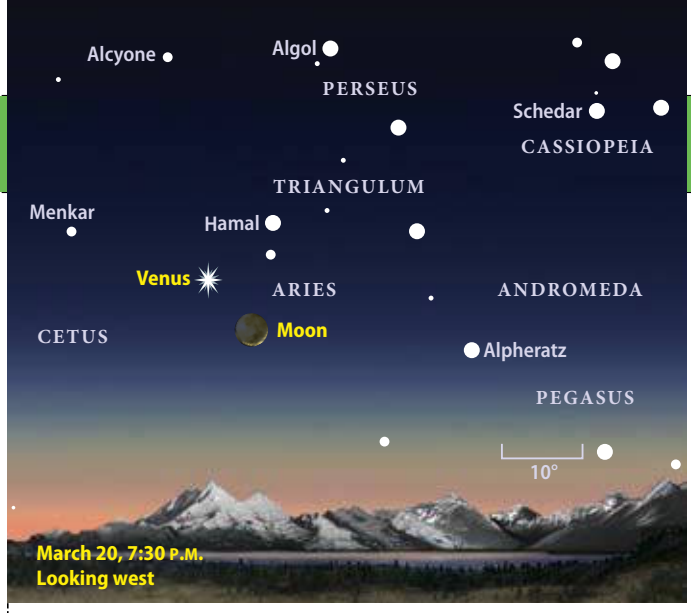
If you can, take a good look with binoculars. Many observers say that the two-eyed view of a deeply colored Moon over the landscape seems surreal. For details, see Phil Harrington's Online Extra this month at www.astronomy.com/toc.

An occultation of a bright star in Leo occurs during this eclipse. The Moon hides 5th-magnitude 59 Leonis during twilight, and the star's reappearance will be observable in small telescopes. Observers in Boston, for example, may catch the reappearance shortly before 7:15 P.M. EST. Get more details for other cities at www.lunar-occultations.com.

One of the nice features of a lunar eclipse is the luxury of time — unlike total solar eclipses, which last mere minutes. Soak in the view: How many shades of ochre do you see? But totality will still end all too soon at 6:58 P.M. EST, so pace yourself accordingly. From the Mississippi River to the Rockies, observers will see a partial eclipse, when the Moon's bright left rim exits the dark umbra during the next hour. Farther west, skywatchers get a deep yellow moonrise after the partial phase has ended, but they'll get their turn August 28, when the next total lunar eclipse occurs.

If you're at a public gathering for the eclipse, encourage visitors to point their digital or video cameras at the eyepiece to take home a keepsake of the event. Most automatic cameras do a decent job capturing totality's copper-red hues, but their small dynamic range cannot show both the sunlit and shadowed portions during the partial phases.

The alignment that makes this lunar eclipse possible also gives rise to a **partial eclipse of the Sun.** On the evening of the 18th, the New Moon takes a bite out of the Sun for observers in northwestern Alaska, northeastern Russia, and Asia.



ASTRONOMY: ROEN KELLY

A THUMBNAIL MOON flirts with Venus March 20. Most of the Moon's disk isn't lit by the Sun then, but the blue-gray glow of Earth — earthshine — faintly lights the whole lunar disk.

Moon meets Venus

Have you ever seen a crescent Moon less than a day old? Look for the breathtakingly thin "Cheshire cat" smile in your sky March 19. Use binoculars to scan the western horizon 45 minutes after sunset. You'll be

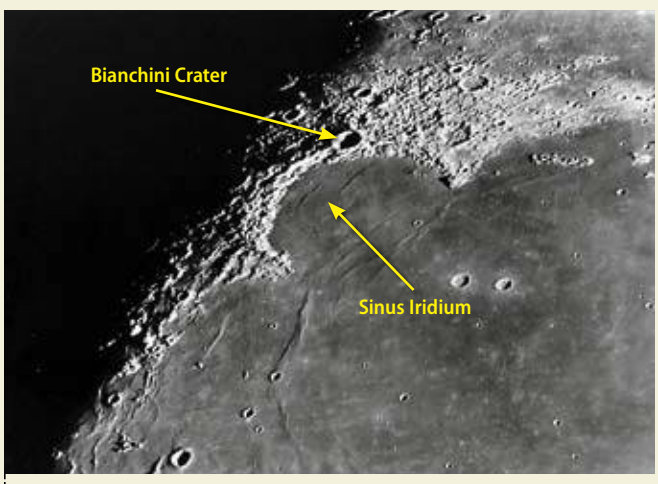
CRATER BY THE BAY

Bianchini Crater is the largest in the walls of the Jura Mountains that surround the Moon's Sinus Iridium. Bianchini is 23 miles wide and has a fresh, young appearance. There's little evidence its walls have slumped or been worn down.

The rim of Sinus Iridium itself is a partially sunken crater. It likely was half-buried when the ground shook following the great Mare Imbrium impact. At low Sun angles, the wrinkled lava plains even give the illusion of waves and currents.

Follow Sinus Iridium's inner wall toward Bianchini. Near the crater, the wall bows out into the basin floor. The impact that made Bianchini plowed material across the lava floor. Bianchini sports a tiny crater in its southeastern wall. It's hard to see unless the Sun is low, when it casts sharp shadows.

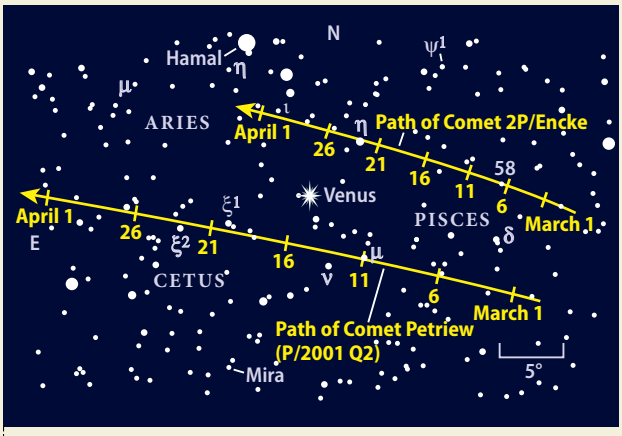
The Sun rises on Sinus Iridium and Bianchini March 28 and 29. Take a look as the shadows play across this rugged region.



CONSOLIDATED LUNAR ATLAS (UA/LPL)

BIANCHINI CRATER PERCHES on the Jura Mountains at the edge of the Moon's Bay of Rainbows. The impact plowed material from the mountains into the bay's lava plains.

Martin Ratcliffe *is the former president of the International Planetarium Society.* **Alister Ling** *is a meteorologist for Environment Canada.*



ASTRONOMY: ROEN KELLY

WEDGED BETWEEN THE PATHS OF TWO COMETS, Venus gleams in the afterglow. Comet Petriew gradually pulls away from Venus, which is shown here March 15.

GOODBYE, PETRIEW. HELLO, ENCKE.

Rarely do we have a chance to watch two comets float through the evening sky in parallel. This month, Comets Petriew (P/2001 Q2) and 2P/Encke lie about 10° apart, twice the width of the Big Dipper's bowl. The comets are really some 15 million miles apart. Their proximity is an illusion of our two-dimensional sky.

Periodic Comet Petriew has just passed perihelion, its closest point to the Sun, and is fading gradually from 10th to 11th magnitude. In contrast, Encke is inbound, heading toward its April perihelion and brightening rapidly from magnitude 11 to 8.

Both of these modest comets are made of ice and dirt. They glow primarily due to sunlight scattering off dust freed from the ice by solar heat. The shroud of light is called the coma, and buried in the middle is a bright point called the false nucleus. The true surface lies hidden from view behind a thick cocoon of dust.

Because neither target is intrinsically bright, you'll have to leave the city to find them under rural skies. The Moon's light ceases to interfere in March's second week. You'll still need to plan carefully because the comets set by mid-evening. Begin looking low in the west 90 minutes after sunset.

On March 15, Comet Petriew is only 4° left of brilliant Venus, while Encke is 9° to the right, as seen from the Northern Hemisphere. Between March 24 and 25, Encke slides less than 1° from the large but dim face-on spiral galaxy Messier 74.

looking for a short yellow-orange arc barely brighter than the background twilight sky. Don't expect to see earthshine, the "old Moon in the new Moon's arms." That occurs the next day, when the Moon will lie closer to Venus.

The sky's majestic clockwork does not play favorites with earthlings, but observers in the western half of North America, who miss the eclipse, get a consolation prize. The thick crescent Moon passes in front of the fabulous Pleiades star cluster on the evening of the 22nd. It's quite fun — and a little eerie — to watch a star abruptly wink out on the Moon's dark limb.

/// WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Venus (west)	Jupiter (southeast)	Mercury (east)
Saturn (east)	Saturn (southwest)	Mars (southeast)
		Jupiter (south)
		Saturn (west)

The spring, or **vernal, equinox** occurs at 8:07 P.M. EDT March 20 when the Sun crosses the equator. This brings shorter, but milder, nights to the Northern Hemisphere. Of more practical importance is the change to daylight-saving time on Sunday morning, March 11. We "spring ahead" 3 weeks earlier than in previous years.

At sunset, **Venus** hangs 30° above the western horizon. Minutes later, it should become visible. As the sky darkens, the brilliance of Venus, shining at magnitude –3.9, becomes apparent. Each day in March, Venus climbs farther away from the Sun. The planet moves along the steeply inclined ecliptic and crosses into the constellation Aries just before St. Patrick's Day.

On March 20, the crescent Moon comes into view 8° from Venus. The extremely thin crescent appears at Venus' lower right, and it ascends to the planet's upper right by March 21. The thin crescent contrasts with Venus' phase, which is visible through any small telescope. On March 1, the disk is 86-percent lit, but this shrinks to 78 percent by month's end.

Simultaneously, the apparent size of Venus' disk grows from 12" to 14", as the planet's distance from Earth diminishes from 130 million miles (March 1) to 114 million miles (March 31). Such changes are explained by the fact that Venus is on a smaller, faster orbit than Earth, and the evening star is catching up to us. By July, the disk will appear 3 times larger and appear as a crescent.

Such observations of Venus through small telescopes were not possible before Galileo's time. This led to a huge misunderstanding of Earth's place in the solar system. The simple observation of Venus' phases put us on the right track.

The planet's run through Aries continues until the end of March. Venus prepares for next month's attractive pairing with the seven sisters, or the Pleiades (M45).

A brilliant Moon stands in the eastern sky March 1 as twilight drapes across the sky. The darkening of the sky will reveal a bright object next to the Moon — it's **Saturn**, the ringed planet. Barely 2 Moon-widths separate them. Saturn shines at magnitude 0 and is easy to pick out before the sky fully darkens.

Saturn is just past opposition and remains visible nearly all night. Located in the constellation Leo, it stands 9° west of Leo's brightest star, Regulus. Saturn, moving retrograde, is migrating slowly west. Next month, its motion will carry it almost to Leo's border with Cancer. Then, the ringed planet halts and turns east again.

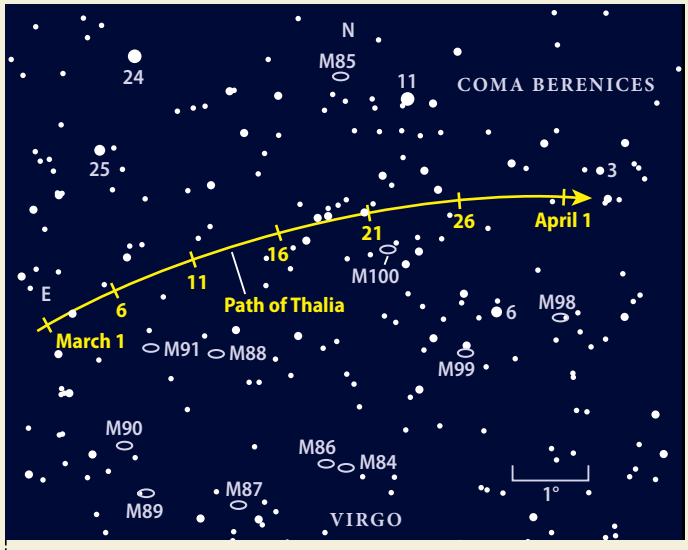
23 THALIA RECEIVES AN ENCORE

Asteroids are given numbers in the order of their discovery and, in more recent times, when their orbits are well known. Because astronomers usually discovered the brightest asteroids first, we usually feature asteroids with low numbers.

But, this month, all the bright asteroids either lie too far from the Sun to make good targets or occupy the other side of the solar system and appear in daylight. To remedy the situation, we turn to 23 Thalia, a space rock that last appeared in these pages about 20 years ago.

Thalia is about 70 miles across, which is another reason it typically loses the brightness challenge against space rocks 3 to 8 times its size. Thalia is coursing through a relatively sparse star field in the constellation Virgo. So, despite the asteroid's current magnitude of 9.8, observers with even a 4-inch scope should be able to pinpoint Thalia.

If you're out doing the Messier marathon around New Moon, take a breather when you arrive at M100, a large face-on spiral galaxy in Virgo. Between March 20 and 21, Thalia lies within 25' of this galaxy's ghostly glow.



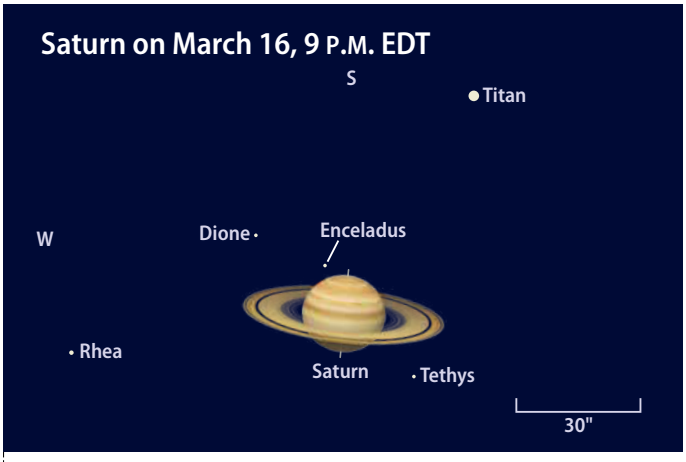
ASTEROID THALIA arcs through a sparsely populated part of the sky during March. Catch it near galaxy M100 March 20/21.

Saturn sports a 20"-diameter disk complete with a fine ring system. The brightest ring, the B ring, lies adjacent to the slightly dimmer and outermost A ring. A dark gap, called the Cassini Division, separates these two rings. Small scopes can show the C ring inside the B ring. The C ring is so thin, the planet's disk shows through it. Following opposition, the planet's shadow appears on the rings' eastern side.

Thanks to Saturn's axial tilt, the rings span 9" by 43". The planet's tilt also lets us glimpse Saturn's polar regions. The planet's most evident feature is the equatorial belt. Even good seeing reveals little else in Saturn's hazy atmosphere.

Tracking the path of the moons around Saturn is easy, especially for the brightest, Titan. Shining at magnitude 8.4, it orbits Saturn every 16 days. You can spot Titan due north of Saturn March 8 and 24, and due south of the planet March 15/16.

Saturn's outermost visible moon is Iapetus. It lies at its fainter eastern elongation far from Saturn during the first week of March. Iapetus glows as faint as magnitude 11.9 and is a nice challenge for small scopes.



SATURN'S MOON TITAN stands south of the planet at midmonth. If you have a telescope that even hints at the presence of Saturn's rings, Titan should be an easy target. *ASTRONOMY:* ROEN KELLY

Brighter moons appear closer to the planet than Titan. Tethys (10.2), Dione (10.4), and Rhea (9.7) are the brightest. Enceladus is more challenging, both because it's fainter (11.5) and because it lies close to Saturn's glare.

As Saturn descends in the western sky after midnight, Jupiter rises in the southeast. On March 1, its brilliant light peeks over the horizon around 3 A.M. local time, and by a couple of hours earlier March 31.

Jupiter brightens a couple of tenths of a magnitude to shine at magnitude –2.3 by March 31. Its yellowish glow contrasts with the red supergiant star Antares, 10° to Jupiter's right. Jupiter itself spends the entire month in the constellation Ophiuchus. A Last Quarter Moon lies less than 10° from Jupiter March 11.

Jupiter remains in the sky until dawn, when it reaches about 30° above the southern horizon. Jupiter's disk reaches 40" across by March 31. Spanning its disk are the dark equatorial belts that carry with them various swirls of atmosphere visible in small scopes. Jupiter's fast spin, one turn in less than 10 hours, moves these features noticeably in just 15 minutes.

Atmospheric features are not the only things moving — Jupiter's four Galilean moons orbit the giant planet in periods from 1.8 to 16.7 days. Io whisks around Jupiter in the fastest period, and if it is anywhere near a line formed by the other three moons, it betrays its motion in a few minutes.

Mars continues its residence in Sagittarius, where it shines at magnitude 1.2. On March 15, Mars lies 8° east of a thin crescent Moon. On the following morning, you'll find Mercury and Mars on either side of the Moon. Mercury makes a brief appearance, although it's rather difficult to observe at magnitude 0.4 in a twilight sky. Binoculars help you spot Mercury: Scan about 9° left of the Moon before sunrise. Don't attempt this after the Sun has risen — you risk catching its blinding rays in your eyes.

Mars remains a telescopic disappointment. The Red Planet must travel millions of miles before the view improves later this year.

The Livio Code

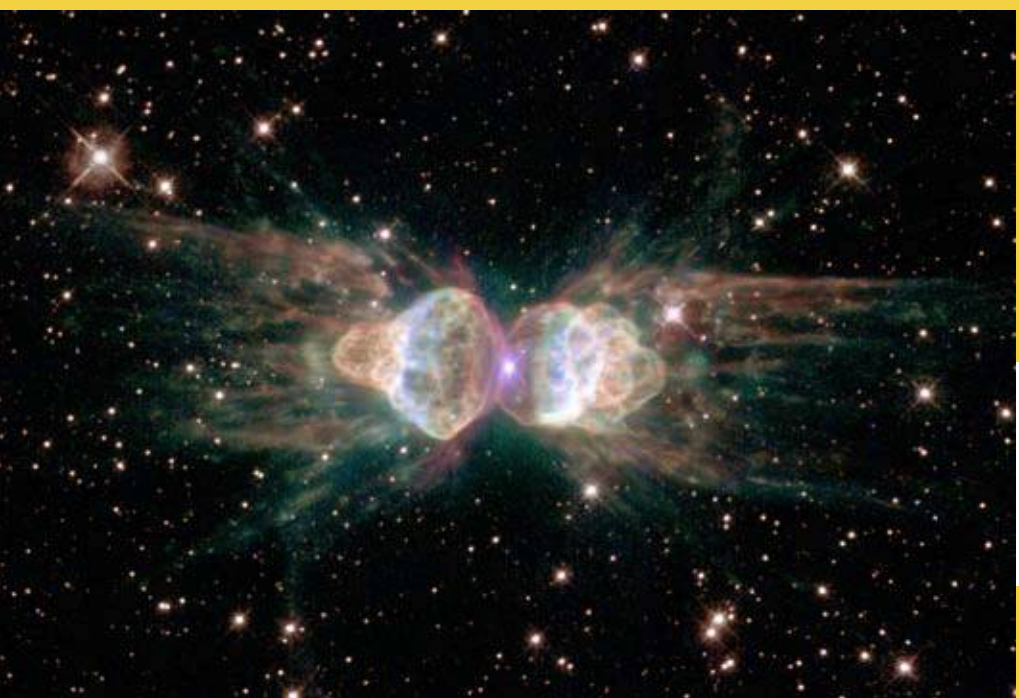
Astronomer Mario Livio believes symmetry rules the universe — from shapes of planetary nebulae to the complexities of the multiverse. /// BY ADAM FRANK

On the 4th floor of the Space Telescope Science Institute in Baltimore, you'll find an office crowded with scientific papers and covered with images of the world's great works of art. The occupant has spent his life searching for universal principles that can unite the diversity astronomers see throughout the cosmos. And he has risen to this daunting challenge with warmth, enthusiasm, and the best of humor.

Mario Livio, a senior astrophysicist and former head of the Institute's science division, is not your average astronomer. From a boyhood in post-World War II Romania to battlefield experience in Israel, he has seen a lot of the world. Now he stands as one of the more prolific and thoughtful astronomers of his generation. His career has spanned 3 decades and covered territory as diverse as the evolution of stars, the creation of planets, the formation of life, and the nature of the universe.

Livio devoted the early years of his career to studying the physics of binary-star interactions. By the early 1990s, he was one of the foremost experts on the topic. He and his student, Noam Soker, applied their expertise to the study of planetary nebulae — the beautiful, luminescent gas clouds blown off dying Sun-like stars. Livio and Soker maintained that when two stars are born locked in close orbits, their individual evolutions can change dramatically. The most extreme example is an event called "common-envelope formation." A common envelope forms when the pair's more-massive star swells into a red giant at the end of its life, engulfing its less-massive companion.

Once the smaller star finds itself inside the massive star's bloated atmosphere, the smaller one's orbit decays from friction. The energy released as the star spirals in blows off the shared outer layer of the semi-merged stars. For Livio and Soker, the ejection of this common envelope offered a mechanism for creating some of the most extreme planetary shapes. It was a big idea and a difficult, elegant piece of physics.

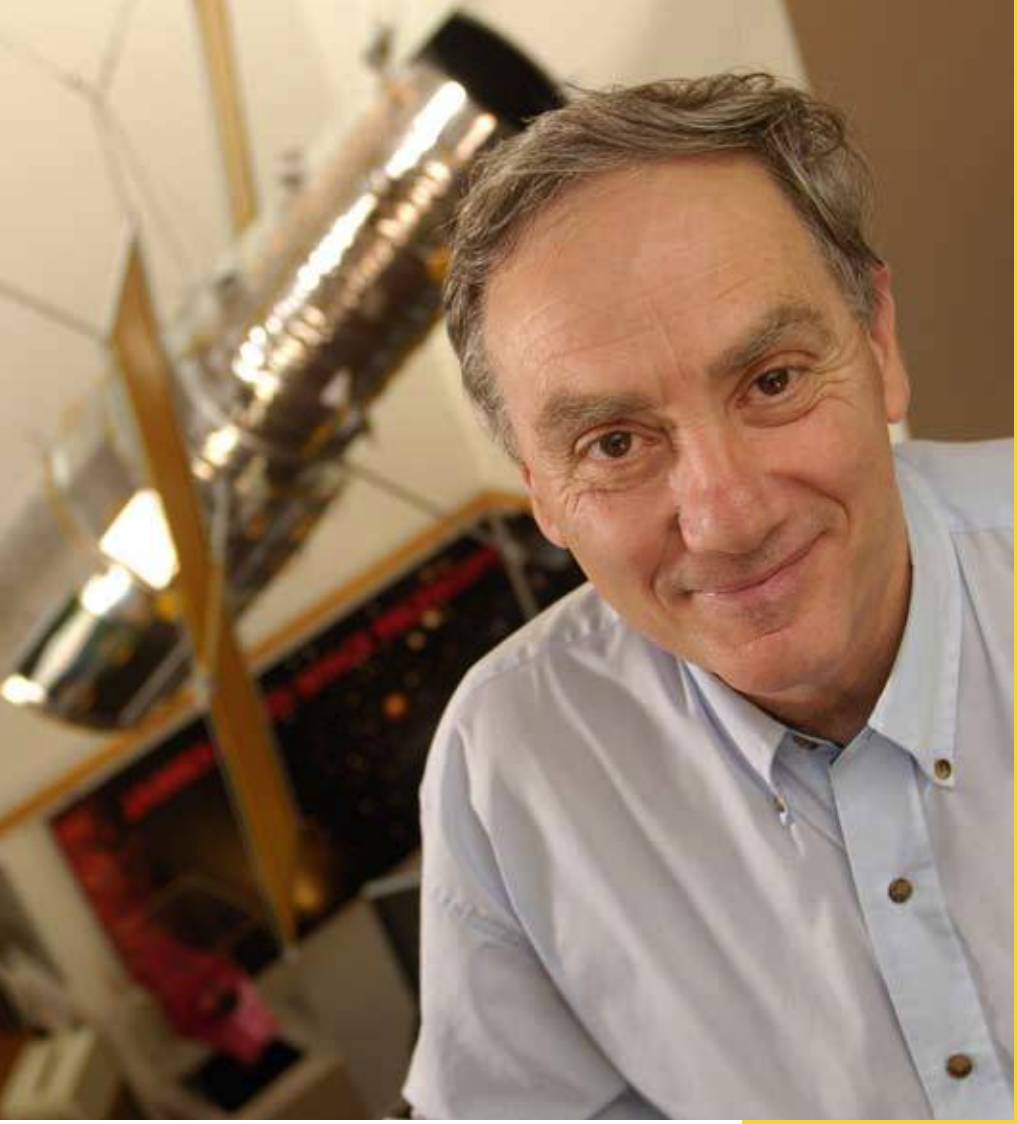


THE ANT NEBULA appears beautifully symmetric, a hallmark of planetary nebulae. Mario Livio thinks the intricate shapes of some planetaries arise through stellar interactions in a binary-star system.

NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Origins

While Livio began his scientific life studying binary stars, he has since explored much of astronomy's varied terrain. His



MARIO LIVIO studies dark energy, extrasolar planets, black holes, and a lot more. There's no better tool for his research than the Hubble Space Telescope, which brought him to the Space Telescope Science Institute. WILL KIRK/HOMEWOOD PHOTOGRAPHIC SERVICES

astronomical traveling has, in this way, mirrored his journeys across the globe.

He was born in Romania in 1945. The immediate postwar period in Eastern Europe was a time of peril and persecution as Soviet troops helped establish repressive regimes. Livio's parents were forced to flee the country and, for the next 5 years, his grandparents raised him. By 1950, the climate for Jews had grown so oppressive that Livio and his family emigrated to Israel, where he spent the next 40 years.

The Jewish state faced its own challenges during that time. Across 4 decades, Livio served in three separate conflicts: the 1967 ("Six Day") war; the 1973 ("Yom Kippur") war, and the 1982 war in Lebanon. The Israeli army trained Livio as a paramedic for a highly mobile field hospital. "We could parachute in, be flown in by helicopters, or be landed by boat," says Livio. "In the Yom Kippur war, we were the only medical unit that crossed the Suez Canal."

In between his participation in these conflicts, Livio completed his academic training. He first earned a master's degree in particle physics and then a doctorate in theoretical astrophysics. From 1981 to 1991, he was a professor of physics at the Teknion-Israel Institute of Technology. Since that time, he has traveled extensively, participating in numerous conferences and workshops.

Adam Frank, *a member of* Astronomy*'s editorial advisory board, is a physicist at the University of Rochester in New York.*

LIVIO SERVED AS A PARAMEDIC in three wars. This picture was taken the day he returned to Israel from the 1973 Yom Kippur war. COURTESY MARIO LIVIO

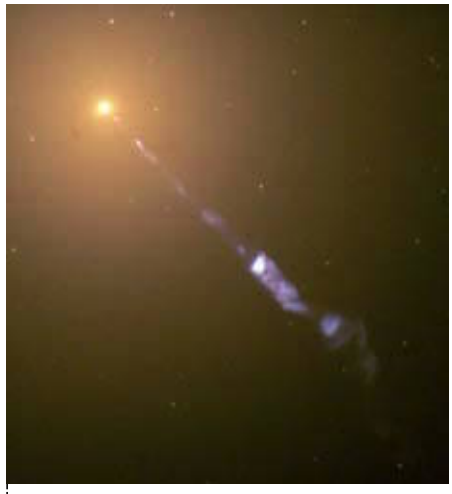
Livio's background in the rarefied realm of particle physics shaped his approach to science. It still determines how he approaches a question, and what kinds of questions he decides to approach. Livio remains interested in the fundamentals. He wants to find general physical principles at work in astronomical phenomena.

"I look for unsolved problems that don't involve any special, individual system," he says. "I was trained as a theoretical physicist, and that means I like problems where the physical processes are what is at stake, not the need to sort through a large collection of data." What makes Livio's approach unusual, however, is his willingness to look for constants across a wide range of particular subjects. His desire to understand the universe at its most basic level takes him into many different arenas.

There are scientists of Livio's bent who would be willing to work on only the

AT 5 YEARS OLD in 1950, Livio (center) posed with his grandparents in Romania. His grandparents raised him until later that year, when they emigrated with him to Israel. COURTESY MARIO LIVIO

THE CAT'S EYE NEBULA developed over many thousands of years as a dying, Sun-like star puffed off its outer layers. The bull's-eye structure came about through cycles of magnetic activity, stellar pulsations, or the action of a stellar companion. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)



THE SUPERMASSIVE BLACK HOLE at the center of the galaxy M87 swallows material and creates a bright jet of high-speed electrons. Along with Livio's many other interests, he studies accretion onto black holes. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

most abstract "fundamental" problems like string theory. Livio has the ability and motivation to move from the "mundane" physics of ordinary stars to the highest realm of astrophysical theory. While his work on binary stars still stands as a milestone in that field, since then, he has published papers on topics as diverse as black holes, planet formation, and the frequency of life in the universe. But the subject that has occupied a great deal of his time recently is the one that takes the search for universals to its roots: cosmology.

A multitude of universes

Back in the old days (some 30 years ago), cosmology meant the study of the Big Bang model and the single universe that emerged from it. Big Bang cosmology, with its elegant explanation for the history of creation, has always drawn astronomers who, like Livio, want to see how far the laws of physics can take us. Beginning in the late 1970s, however, a hornet's nest of paradoxes appeared in the very data astronomers used to confirm the Big Bang. While still successful, the Big Bang found itself in big trouble.

To resolve the difficulties, astronomers added a crucial new element to their picture of creation. They called this add-on

MARIO LIVIO'S UNIVERSE

You remember the first time you meet Mario Livio. For me, it came at a 1992 conference on planetary nebulae in Innsbruck, Austria. In 1992, the origin of these remarkable cosmic sculptures posed a challenge to astronomers studying them.

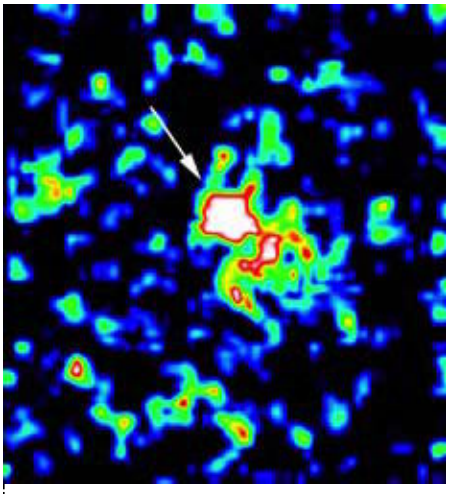
That summer, I was a newly minted Ph.D. giving my first talk at an international conference. I had, of course, heard of Livio. Every young student there knew of him. Livio, in collaboration with his student Noam Soker, had written a series of provocative studies arguing for a strong link between binary stars and the shapes of planetary nebulae.

A planetary nebula is a gorgeous cloud of ionized gas ejected by a Sun-like star near the end of its life. It is, essentially, the star's last gasp before it fades into a cinder known as a white dwarf. Planetary nebulae come in a wild variety of shapes — everything from perfect spheres to crazy butterfly patterns.

When Livio walked to the podium, I saw a man of medium height with dark hair and handsome features. He paused for a moment and then, in a voice booming with exuberance but softened by an Israeli accent, he proceeded to enthrall the audience. With deft use of derivations, metaphors, and ample gesticulations, he presented a forceful argument for binary stars being the agents shaping planetary nebulae.

Later in the conference, I got to meet Livio and talk science. I was impressed with his kindness and generosity as much as by his passion for exploring how the universe is built. In the years since, the qualities he showed that day have been a constant in my dealings with him. — *A. F.*

HUBBLE STANDS WATCH over Livio at STScI. WILL KIRK/HOMEWOOD PHOTOGRAPHIC SERVICES



A POWERFUL GAMMA-RAY BURST erupts in the distant universe. Mario Livio was a member of the team that studied GRB 970228 and showed these exotic blasts are the most powerful explosions in the universe. K. SAHU/M. LIVIO/L. PETRO/D. MACCHETTO/STScI AND NASA

HUBBLE ASTRONOMERS found 16 exoplanet candidates in the direction of our galaxy's center. Livio served on the team that discovered these transiting "hot Jupiters" among some 245,000 observed stars. NASA/ESA/K. SAHU (STScI) AND THE SWEEPS SCIENCE TEAM

"inflation," and it steps into the story around 10^{-35} second after the Big Bang. At this instant, inflation takes a small piece of the nascent universe, separates it from the background, and drives it through a brief period of hyperexpansion. This little corner of creation gets "inflated" and swells to become the entire cosmos we will ever see or experience. In other words, what starts as a tiny shred of reality becomes our entire universe. Inflation rescued the Big Bang from itself, giving it new life and new explanatory powers.

Inflationary cosmology is now the dominant model for understanding cosmic history. But if inflation blows up a shred of creation into our whole universe, what happened to the rest of it? This question remains very much on Livio's mind.

"Inflation changed the status of our universe," says Livio. Instead of being everything, our universe was degraded to a piece embedded in something far bigger. Livio likes the term "pocket universe" to describe what we used to think of as the entirety of creation.

It took a decade or so after inflation appeared for astrophysicists to realize other pocket universes could inflate out of the background. If it happened once, it could happen again. In fact, these other universes might still be forming now. "People called this idea 'eternal inflation,'" explains Livio. "Pocket universes are continually created, and the sum total of these pocket universes is what we now call the multiverse."

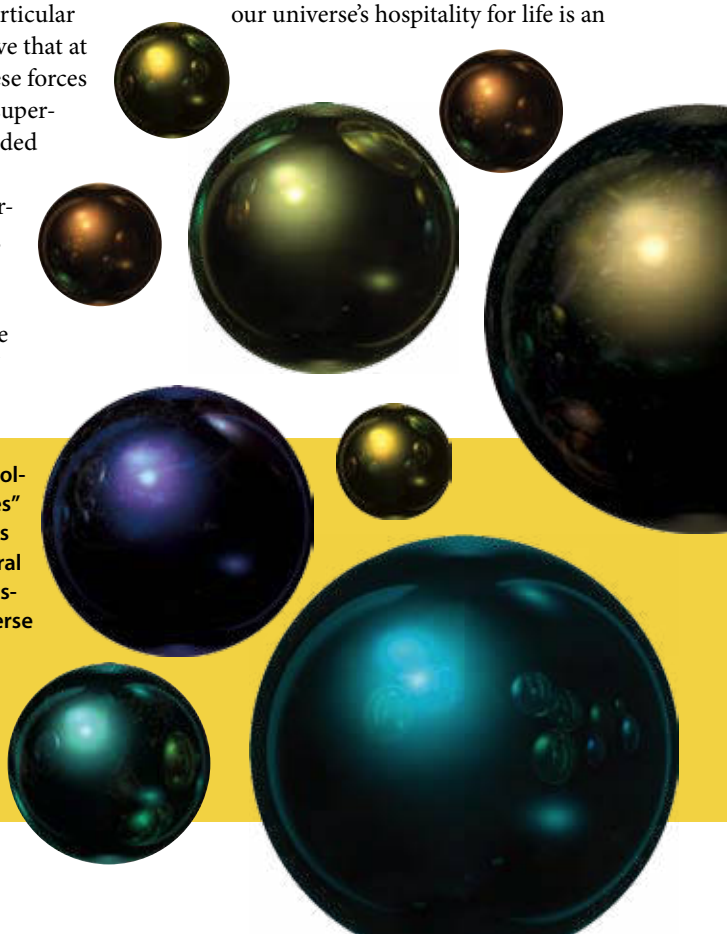
The multiverse — think of it as a universe of universes — is a wonderfully weird idea on its own terms. But for Livio, the fascination focuses on the way the laws of physics get expressed in the multiverse. He explains that every pocket universe could get its own version of these laws. Each universe could be unique. "In our universe," Livio begins, "there are 4 forces [gravity, electromagnetism, and the strong and weak nuclear forces], each with its own particular form and strength. We believe that at the time of the Big Bang, these forces were all merged in a single 'superforce.' As the universe expanded and cooled, the four forces 'froze out' of the primal superforce. With eternal inflation, the forces in each pocket universe could freeze out in different ways. Each universe could get a different form of physics and a different fate."

A multiverse containing multiple forms of physics makes Livio's job of looking for universal principles more difficult — and more interesting. Rather than search for the laws determining the structure of a single universe, he and his colleagues now must find the general principle that determines all the general principles in all the pocket universes. Lurking in this speculation is the unsettling possibility that the heart of such a new principle may lie in randomness.

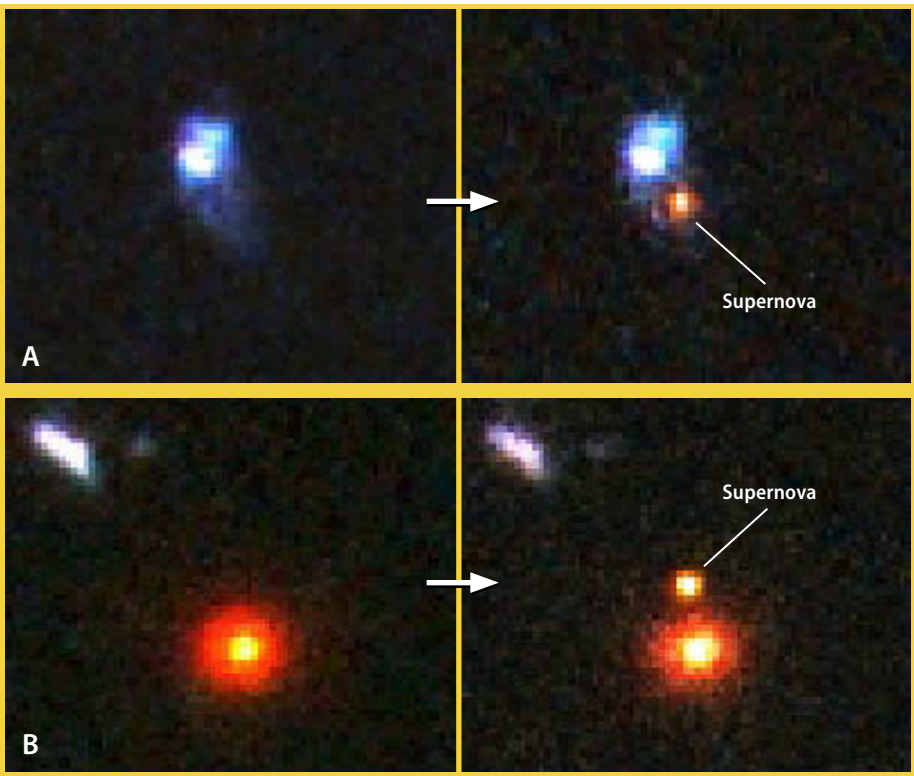
"What we want," says Livio, "is a self-consistent cosmological theory where everything is determined from fundamental physics. We do not have such a theory, and the multiverse may imply that we have to keep an open mind about the role of randomness in fundamental physics." For Livio, the multiverse challenges scientists to understand what they really mean by terms like "general" and "fundamental."

"Five hundred years ago, people looked at the solar system and thought the number of planets was somehow fundamental," he explains. "Now we know the number of planets is random even though the process that makes planets is based on general principles we do understand."

Livio speculates that the form and strength of some forces in any pocket universe may be random, just like the number of planets in a solar system. In that case, our universe's hospitality for life is an



THE MULTIVERSE — the collection of "pocket universes" (including ours) that makes up all creation — is a natural outcome of inflationary cosmology. Each pocket universe has its own set of physical laws. Livio seeks to understand the principles of the multiverse that create the pocket universes. *ASTRONOMY:* ROEN KELLY AND CHUCK BRAASCH



DISTANT SUPERNOVAE prove dark energy dominates the cosmos and the universe's expansion is currently speeding-up. In explosions A and B, the left panel shows only the host galaxy, while the right panel also records a supernova. NASA AND A. RIESS (STScI)

accident but, statistically speaking, a reasonable accident.

Doing physics in a multiverse presents enormous challenges because every pocket universe is disconnected completely from every other. It's not even clear how to make statistics work across a multiverse. But Livio sees these challenges as stepping-stones to questions that touch deeper levels of physical reasoning. "If I have a self-consistent theory that explains the observable universe but it predicts a random distribution of physics in the other pocket universes, what should I do?" he asks. "Should I accept such a theory or reject it until a theory without randomness comes along?"

Symmetry and beauty

There are deeper levels to plumb for a generalist like Livio. After asking which laws of physics determine structures like planetary nebulae and what principles determine the physics of the multiverse, Livio is now ready to go even further. In his popular books, Livio has taken hundreds of thousands of readers on thought-provoking explorations of the source of physical reasoning itself.

Livio's books often ask how science works by exploring the realm of mathematics, the foundation of all physical laws. In this most fundamental of fundamental territories, Livio sets his self-described inner "art fanatic" free to roam. Art and science are not entirely separate domains in his mind. In his first book, *The Accelerating Universe*, he explored the astrophysics of dark energy and the relationship between mathematical beauty and truth in cosmology. In *The Golden Ratio*, mathematical beauty appeared again as he explored how artists and scientists have used the number phi (1.61803…) during the past 2,500 years.

In his most recent book, *The Equation that Couldn't Be Solved*, Livio moves across 200 years of history to explore the fundamental concept of symmetry. It's an idea that underpins the entire enterprise of science. "Symmetry means the immunity to change," he explains. "There are all kinds of symmetries. Some shapes look the same no matter how you rotate them. That is one obvious kind of symmetry, but there are many others, some that exist only in the abstract realm of mathematical physics."

According to Livio, these symmetries allow physics to be applied universally. "Cosmology relies on the laws of physics within our pocket universe not changing anywhere in space or time," he says. "From the Big Bang to the present day, that symmetry is necessary for us to say anything meaningful about the universe." The connections of science with art appear again in this book, as Livio explores the subtle ways artists either use or play against symmetry to create works of beauty.

In his popular talks, Livio exudes his typical confidence, enthusiasm, and warmth. On a warm spring day in 2005, I took my 10-year-old son and 13-year-old daughter to see Livio present a popular lecture on the golden ratio. As the audience filed into the auditorium at the Rochester Institute of Technology, he saw me and came over to say hello. He made a point of speaking right to my kids with his usual gentle directness.

Then it was time to start the lecture and, for the next hour, it was pure Mario — an energetic whirlwind tour of the golden ratio appearing in architecture, painting, biology, and physics. We all left with our heads stuffed with new ideas. On the drive home afterward, my hard-to-impress 13-year-old summed it up concisely.

"Wow," she said. "He was pretty cool." A

LIVIO SEARCHES FOR SYMMETRY in the objects he studies and in the principles that underlie science. In his office at STScI, he ponders symmetry and how it "is necessary for us to say anything meaningful about the universe." WILL KIRK/HOMEWOOD PHOTOGRAPHIC SERVICES

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IMAGINOVA

Spacecraft landings

Touchdowns on other worlds

Thirty-nine spacecraft have returned data from 6 worlds. /// BY FRANCIS REDDY

Space exploration is risky and expensive, but its greatest success — returning information from the surfaces of other worlds — is a novel testament to humanity's quest for new vistas.

The first target, naturally enough, was the Moon. In 1966, the Soviet Luna 9 and American Surveyor 1 missions set down on the Moon's dusty "seas." Incredibly, just 3 years later, U.S. astronauts followed these robotic landers.

In 1970, Soviet persistence in a Venus landing paid off with Venera 7. The following year, Mars 3 died seconds after landing on the Red Planet. In 1976, NASA's Viking 1 and 2 became the first successful Mars landers. Decades later, NASA's Near Earth Asteroid Rendezvous (NEAR) probe became the first to settle onto an asteroid (Eros). In 2005, Japan's Hayabusa did likewise on Itokawa.

The European Space Agency's Huygens probe, which rode to Saturn aboard NASA's Cassini spacecraft, made the most distant touchdown. On January 14, 2005, it returned the first images from the surface of Titan, Saturn's frigid, cloud-shrouded moon.

Itokawa

JAXA

Hayabusa
Japan, Nov. 20, 2005
Attempted sampling of an asteroid

HAYABUSA imaged its shadow while descending toward a marker (circled) it had dropped onto Itokawa. JAXA

Eros

Near Earth Asteroid Rendezvous (NEAR Shoemaker)
U.S., Feb. 12, 2001
First landing on an asteroid

NASA/JHUAPL

The Moon

JAMES IRWIN boards the Lunar Rover during the Apollo 15 mission. NASA

Apollo 15
U.S., July 30, 1971
David Scott, James Irwin, fourth piloted landing

Mare Imbrium

Luna 17/Lunokhod 1
U.S.S.R., Nov. 17, 1970
The remote-controlled Lunokhod rover operated for 11 months.

Luna 21/Lunokhod 2
U.S.S.R., Jan. 15, 1973
The rover traveled 22 miles (37 km) in 4 months of operation.

Apollo 17
U.S., Dec. 11, 1972
Eugene Cernan, Harrison Schmitt, sixth piloted landing

Luna 23
U.S.S.R., October 28, 1974
Attempted sample return; sampler damaged on landing

Luna 24
U.S.S.R., Aug. 18, 1976
Sample return

Alba Patera

Luna 20
U.S.S.R., Feb. 21, 1972
Sample return

Luna 16
U.S.S.R., Sept. 20, 1970
Collected lunar samples and returned them to Earth

Tharsis Tholos

Surveyor 5
U.S., Sept. 10, 1967

Apollo 11
U.S., July 20, 1969
Neil Armstrong, Buzz Aldrin, first piloted lunar landing

Oceanus Procellarum

Luna 13
U.S.S.R.
Dec. 24, 1966

Apollo 12
U.S., Nov. 19, 1969
Charles Conrad, Alan Bean, second piloted landing

Surveyor 6
U.S., Nov. 9, 1967

Surveyor 3
U.S., April 20, 1967

Apollo 14
U.S., Feb. 5, 1971
Alan Shepard, Edgar Mitchell, third piloted landing

Luna 9
U.S.S.R., Feb. 3, 1966
First controlled landing on another celestial body

Valles Marineris

Apollo 16
U.S., April 21, 1972
John Young, Charles Duke, fifth piloted landing

BUZZ ALDRIN imaged his footprint in lunar soil. NASA

A LUNAR ROVER awaits Apollo 16 astronauts. NASA

Surveyor 1
U.S., May 30, 1966
The Surveyors obtained lunar-surface images and data in preparation for human landings.

ALAN BEAN steps down the lunar module's ladder. NASA

Surveyor 7
U.S., Jan. 9, 1968

Tycho

T. A. RECTOR AND I. P. DELL'ANTONIO/NOAO/AURA/NSF

Venus

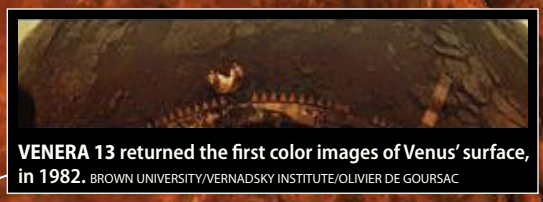
Maxwell Montes

Beta Regio

Venera 9
U.S.S.R., Oct. 22, 1975
First image returned from another planet's surface

Venera 10
U.S.S.R, Oct. 25, 1975

Venera 13
U.S.S.R., March 1, 1982
First color images from Venus' surface



VENERA 13 returned the first color images of Venus' surface, in 1982. BROWN UNIVERSITY/VERNADSKY INSTITUTE/OLIVIER DE GOURSAC

Venera 12
U.S.S.R., Dec. 21, 1978

Venera 14
U.S.S.R., March 5, 1982

Venera 7
U.S.S.R., Dec. 15, 1970
First spacecraft to return data from another planet's surface

Phoebe Regio

Venera 8
U.S.S.R., July 22, 1972

Venera 11
U.S.S.R., Dec. 25, 1978

Alpha Regio

Atla Regio

Rusalka Planitia

Vega 1
U.S.S.R., June 11, 1985
Successful Venus lander and Comet Halley flyby

Vega 2
U.S.S.R., June 15, 1985
Mission identical to Vega 1

Pioneer Venus Day probe
U.S., Dec. 9, 1978
One of four separate atmospheric probes unexpectedly survived surface impact and transmitted for more than an hour

USGS/NASA/FRANCIS REDDY

Mars

THE SOJOURNER rover analyzes a rock at the Mars Pathfinder site in 1997. NASA/JPL

VIKING 2 imaged a patina of frost at its landing site in 1979. NASA/JPL

Viking 1
U.S., July 20, 1976
Returned data from Chryse Planitia for more than 6 years

Mars Pathfinder
U.S., July 4, 1997
Both the lander and the Sojourner rover it carried returned data from Ares Vallis for nearly 4 months.

Viking 2
U.S., Sept. 3, 1976
Operated more than 3.5 years on Utopia Planitia

Elysium Mons

Opportunity rover
U.S. Jan. 25, 2004
Operations continue at Victoria Crater, Meridiani Planum

FOLLOWING A 5-mile (9 kilometer) drive, Mars Exploration Rover Opportunity returned this image from the rim of Victoria Crater. NASA/JPL

Argyre Basin

Spirit rover
U.S., Jan. 4, 2004
Operations continue at Gusev Crater

Mars 3
U.S.S.R., Dec. 2, 1971
Failed after transmitting for 20 seconds; may have deployed a tiny rover

USGS/NASA/FRANCIS REDDY

Titan

NASA/JPL/SSI

Huygens
European Space Agency, Jan. 14, 2005

Xanadu Regio

HUYGENS REVEALED what appears to be a dry stream bed formed by flowing methane on Saturn's moon Titan. ESA

Astronomy magazine

These easy-to-observe objects offer a variety of smoke rings, spheres, and colored disks. /// **BY STEVE GOTTLIEB**

See winter's best planetary nebulae

English astronomer William Herschel

began his survey of the heavens in 1783. He encountered several small, striking, symmetrical nebulae. They looked similar to Uranus' blue-green disk Herschel had discovered in 1781, so he dubbed them "planetary nebulae."

A planetary nebula's formation begins with an aging red-giant star. An outflowing stellar wind gently expels the star's outer atmosphere. As the star depletes its nuclear fuel supply, instabilities accelerate the outflow and expose the star's smoldering, dense core — a white dwarf. An energetic stellar wind from the white dwarf plows into the previously ejected material, compressing and sculpting the gas.

Although many planetaries appear as symmetrical disks or rings, long-exposure images reveal a wild menagerie of exotic shapes: multiple rings and shells, butterfly wings, and expanding knots called FLIERS (fast, low-ionization emission regions).

Steve Gottlieb *is a long-time deep-sky aficionado who resides in northern California.*

Many planetaries have a high surface brightness. This allows you to use high magnification to resolve structure and, possibly, reveal the white dwarf, rings, outer halos, and bipolar lobes. Planetaries glow predominantly in the green light produced by doubly ionized oxygen (at about 500.1 nanometers). Narrowband filters, such as an OIII filter, increase the contrast between a nebula and the background sky. A filter improves the view from either a dark or light-polluted site. The winter Milky Way is home to many remarkable planetaries. Follow along on this tour of my favorite 10.

Start in Perseus

Begin with the **Little Dumbbell Nebula** (M76), located just 1° north-northwest of 4th-magnitude Phi (ϕ) Persei. M76 is a superb example of a bipolar planetary, exhibiting two symmetric outer wings. Herschel described M76 as "two, close together, both very bright," and it received two NGC numbers: 650 and 651. A 6-inch scope will display this elongated double structure with the southwest lobe more prominent.

Seen through my 18-inch reflector, the two mottled lobes bracket a darker center. Adding an OIII filter to the eyepiece shows a larger halo surrounds this main structure, and two sweeping outer "wings" emerge within this halo. The wings' appearance mimics a barred spiral galaxy. The "arm" attached at the northeast end sweeps around toward the west and doubles the nebula's apparent diameter.

Across the border to Taurus

Herschel discovered **NGC 1514** in November 1790 using his 18.5–inch speculum mirror (a brittle alloy of copper and tin). The nebula's appearance was so striking that it caused him to rethink the prevailing view that nebulae were all unresolved stellar aggregates.

After observing NGC 1514, he wrote "A most singular phenomenon! A star of about 8th magnitude with a faint luminous atmosphere of circular form, and about 3 minutes in diameter. The star is perfectly in the center and the atmosphere is so delicate, faint and equal throughout that there can be no surmise of its consisting of stars; nor can there be a doubt of the evident connection between the atmosphere and the star." Herschel speculated a luminous fluid was responsible for this phenomenon.

A 6-inch scope reveals a delicate 1'-wide halo surrounding a magnitude 9.4 central star. Use a narrowband filter. It will cut

NGC 1514 in Taurus lies 3.5° east-southeast of Zeta (ζ) Persei. This magnitude 10.9 planetary has a 1'-wide inner shell marked by bright knots of material. ADAM BLOCK/NOAO/AURA/NSF

NGC 1501 lies 7° west of Beta (β) Camelopardalis. This faint blue-gray planetary glows at 12th magnitude and measures almost 1' across. ADAM BLOCK/NOAO/AURA/NSF

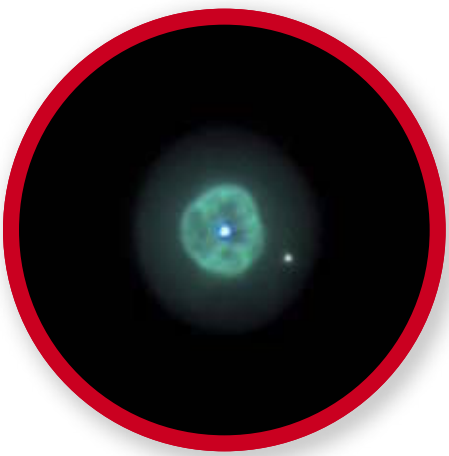
down the star's glare and enhance the nebulosity. Through my 18-inch scope and an OIII filter, the halo increases to nearly 2.5' in diameter and the surface brightness becomes noticeably uneven, with the halo's northwest quadrant clearly brighter. A small, darker "hole" surrounds the central star, and the irregularly lit halo contains a bright "knot" on the southeast side. NGC 1514 resides 3.5° east-southeast of 3rd-magnitude Zeta (ζ) Persei.

North to the Giraffe

NGC 1501 in Camelopardalis lies near Kemble's Cascade, a wonderful 3°-long chain of 20 stars at 8th magnitude that tumbles from northwest to southeast. On the cascade's southeast side is the bright open cluster NGC 1502, and our planetary target resides less than 1.5° due south. A 6-inch scope shows a 45"-wide, crisp blue-gray disk with no central star. Through my 18-inch at 280x, a magnitude 14 central star shines steadily, and the disk extends slightly from southwest to northeast. In good conditions, the outer rim appears mottled or clumpy and a small, darker center is visible around the central star.

Planetaries down south

NGC 1535 has long been one of my favorites. This gorgeous planetary shows a concentric double-shell structure and pale blue-green color. You can find it 4° east-northeast of 3rd-magnitude Gamma (γ) Eridani. A 6-inch scope displays the bright inner disk and hints of an outer envelope.



NGC 1535 appears similar to the Eskimo Nebula (NGC 2392) in both structure and color. Use a 12-inch or larger telescope to see NGC 1535's pale blue-green hue. This magnitude 9.4 object lies more than 5,000 light-years away. ADAM BLOCK/NOAO/AURA/NSF

THE LITTLE DUMBBELL NEBULA (M76) in Perseus ranks as the faintest object on Messier's list. This magnitude 10.1 planetary nebula measures 2.6' by 1.6' and lies 3,400 light-years from Earth. ADAM BLOCK/NOAO/AURA/NSF

With my 18-inch at 380x, the planetary appears round with a slightly elongated, striking blue inner ring 20" across. The inner portion exhibits small, dark gaps immediately surrounding the magnitude 12.5 central star. A faint outer envelope encompasses the inner shell and roughly doubles the object's diameter.

Herschel's son, John Herschel (1792–1871), seemed confused with NGC 1535's classification because his notes read, "A mottled disk, but so hazy at the borders that I have no doubt of its being a very distant and highly compressed globular cluster. It is not a planetary, though a near approach to one." Take a close look, and see if you agree with his description.

The **Butterfly Nebula** (NGC 2346) in Monoceros is a beautiful bipolar planetary with a bright, oval disk and large outer lobes that form celestial wings to the northwest and southeast. The magnitude 11.5 central star is a close spectroscopic binary. Also known as V651 Mon, this well-studied eclipsing variable star dips to magnitude 13.5 during each 16-day orbit.

Locate NGC 2346 by scanning less than ¾° southwest of 4th-magnitude Delta (δ) Monocerotis. A 6-inch telescope with a narrowband filter will reveal a faint disk 30" across surrounding the central star.

THE BUTTERFLY NEBULA (NGC 2346) classifies as a bipolar planetary nebula. Large gaseous lobes form the butterfly's "wings." This object's central star is a close eclipsing binary. During its 16-day period, its magnitude changes from 11.5 to 13.5. DOUG MATTHEWS AND CHARLES BETTS/ADAM BLOCK/NOAO/AURA/NSF

Through my 18-inch scope, the irregular, mottled disk extends to 50". This nebula has a pinched corner on the northwest side and a hint of a larger gossamer halo.

The **Spirograph Nebula** (IC 418) is a compact, high-surface-brightness planetary in Lepus that appears as a 10th-magnitude star at low power through a 4-inch scope. A common search technique is to "blink" for such diminutive planetaries. Carefully move a narrowband filter (a Hydrogen-beta filter works well with this type of object) in and out between the eyepiece and your eye. Search for a point (the planetary) that stays bright when seen through the filter while the surrounding stars dim. Once you've identified the planetary, high magnification will tease out a small halo surrounding the magnitude 10.5 central star.

PLANETARY TARGETS

USE THIS FINDER CHART to locate the planetary nebulae in this story. We've set the chart to show mid-winter stars an hour past sunset. *ASTRONOMY*: ROEN KELLY

THE SPIROGRAPH NEBULA (IC 418) shines at magnitude 9.3 and lies a bit more than 5° north-northwest of Arneb (Alpha [α] Leporis). The Hubble Space Telescope's Wide Field Planetary Camera 2 captured this false-color image. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

The Hubble Space Telescope revealed an amazing, intertwined mesh of filaments weaving through this planetary, similar to a spirograph drawing. Although this structure is not visible in the eyepiece, the Spirograph Nebula does display a reddish hue through large telescopes. Through my 18-inch at 100x, a 10"-wide halo with a rosy tint at its outer edge surrounds the central star. Higher magnification displays the halo better but subdues the color.

Although many planetary nebulae are small in stature and may get lost in rich Milky Way fields, don't pass them over for splashier objects. They provide wonderful targets to hone your observing skills, and, with experience, you'll discover their delicate beauty.

Over to Puppis

The rich open cluster M46 in Puppis is a winter star-party favorite with a uniform carpet of 100 to 200 stars spread over 30'. The annular planetary nebula **NGC 2438** adorns the cluster on the northeast side. Although it appears to float among the dense mat of stars, the planetary is superimposed on the cluster. NGC 2438 lies 2,900 light-years distant, while M46 sits roughly 5,400 light-years from Earth.

French comet-hunter Charles Messier (1730–1817) discovered the cluster in 1771 but missed the planetary due to his instruments' relatively poor quality. Today, a 4-inch telescope reveals this celestial bubble. Through an 8-inch scope, it displays a dark center. Through my 18-inch, the planetary spans 70" at 320x. At this power, an irregular ring is prominent, and a 20"-wide center glows weakly. A 13th-magnitude star (not the central star, however) is just northwest of the center, and a second fainter star lies nearby, toward the southwest. An 11th-magnitude star hugs the southeast edge.

NGC 2440 is a remarkable bipolar planetary William Herschel discovered in 1790. He succinctly described it as a "beautiful planetary nebula." Photographs reveal an

NICOLE BIES AND ESIDRO HERNANDEZ/ADAM BLOCK/NOAO/AURA/NSF

NGC 2438 appears superimposed on the northern side of open cluster M46 in Puppis. Although this planetary measures only about 1' across, a 4-inch scope easily reveals it.

NGC 2440 resides in Puppis 13.6° east of Sirius (Alpha [α] Canis Majoris). This 9th-magnitude planetary nebula has a chaotic structure and lies about 4,000 light-years away. JEFF CREMER/ADAM BLOCK/NOAO/AURA/NSF

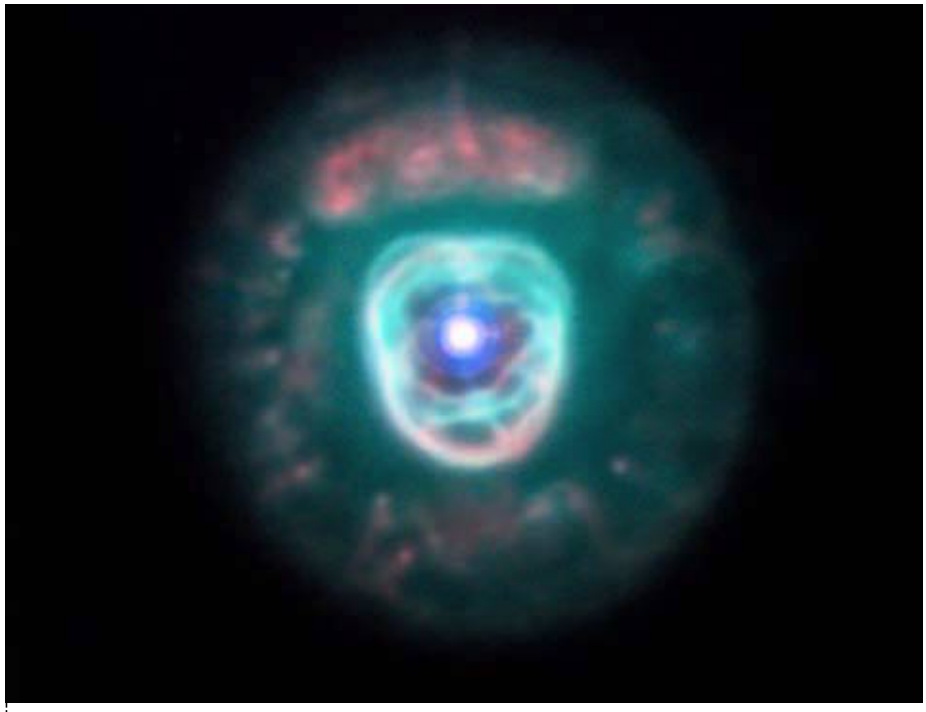
amazing, complex structure with internal filaments, gas blobs, and two lobes. The magnitude 18 central star is a scorcher, with a temperature of roughly 360,000° F (200,000° C). That's more than 30 times the Sun's temperature, and it ranks this star as one of the hottest known white dwarfs.

Find NGC 2440 by dropping 3.4° south from M46. A 6-inch scope at 75x easily reveals a small, hazy oval 20" to 25" in diameter. Through my 18-inch scope, the view is extraordinary at 380x. The bright, boxy inner region contains two knots. A faint outer halo is oriented southwest to northeast with two wings similar to a galaxy's spiral arms. The nebulosity is weaker to the southwest where a cup-shaped dark notch protrudes into the central region.

End in Gemini

When William Herschel ran across the **Peanut Nebula** (NGC 2371–2) in 1785, he assumed it was a double nebula and cataloged each lobe separately. To locate the Peanut Nebula, start at Castor (Alpha [α] Geminorum) and sweep 3° southwest. Through a 6-inch telescope, you'll find only a small, hazy patch, but 10-inch and larger scopes will resolve this unusual planetary's bipolar nature. John Herschel was confused by the structure, which he described as a "curious, bright double nebula or an elongated bi-central nebula."

Through my 18-inch at 380x, I can resolve two bright lobes oriented southwest to northeast with 30" of separation. Each knot measures 15" to 20" across with the southwest knot the brighter of the pair. A weak bridge of nebulosity spans the two knots, giving a "dog bone" appearance.



PETER AND SUZIE ERICKSON/ADAM BLOCK/NOAO/AURA/NSF

THE ESKIMO NEBULA (NGC 2392) looks like its namesake because of overlapping, expanding gas shells. This 9th-magnitude object lies about 3,000 light-years away.

Our final object — the **Eskimo Nebula** (NGC 2392) — is a double-shelled showpiece described by William Herschel as a "star of 9th magnitude with pretty bright, milky nebulosity equally dispersed all around." In early photographs, vague facial features in the interior and a detached outer shell inspired the nickname. But recent Hubble images show the interior contains a maze of intersecting filaments, and the hood resolves into an array of radial jets.

To find the Eskimo Nebula, look 2.4° east-southeast of magnitude 3.5 Delta Geminorum. A 6-inch scope at 50x reveals a small blue disk dominated by a magnitude 9 central star. Through my 18-inch, the view is mesmerizing at 800x — the white dwarf is surrounded by a darker hole within an irregularly lit annulus 20" across. A dark, narrow moat divides the inner shell from a large, low-surface-brightness outer halo nearly 1' in diameter.

Winter may not be your favorite observing season. As you center one after another of these spectacular planetary nebulae in your eyepiece's field of view, however, you'll hardly notice the chill in the air.

ONLINE EXTRA Get cold-weather observing tips at www.astronomy.com/toc.

/// TEN PLANETARY TREATS

Name	Constellation	R.A.	Dec.	Size	Magnitude
M76	Perseus	1h42m	1°34'	163" by 107"	10.1
NGC 1501	Camelopardalis	4h07m	60°55'	56" by 48"	11.9
NGC 1514	Taurus	4h09m	30°47'	136" by 121"	10.9
NGC 1535	Eridanus	4h14m	–12°44'	48" by 42"	9.4
IC 418	Lepus	5h28m	–12°47'	40" by 35"	9.3
NGC 2346	Monoceros	7h09m	–0°48'	60" by 50"	11.9
NGC 2371–2	Gemini	7h26m	29°29'	74" by 54"	11.2
NGC 2392	Gemini	7h29m	20°55'	47" by 43"	9.2
NGC 2438	Puppis	7h42m	–14°44'	73" by 68"	10.8
NGC 2440	Puppis	7h42m	–18°13'	74" by 42"	9.3

Key: R.A. = Right ascension; Dec. = Declination; both coordinates are 2000.0.

MARTIN AND JAN DE WET/ADAM BLOCK/NOAO/AURA/NSF

THE PEANUT NEBULA (NGC 2371–2) exhibits two bright lobes through telescopes 10 inches or more across. Because of its twin nature and the constellation in which it lies, astronomers also refer to NGC 2371–2 as the Gemini Nebula.

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At ***astronomics***, we specialize in telescopes and always have. Our family-owned business has been helping people choose the right telescope since 1979. We have the experience (a staff total of over *150 years* of experience and accessories named *Hot Products* by *Sky & Telescope Magazine*. Here are just a few of the *Hot Products* you'll find in stock at ***astronomics*** . . .

A passel of *Hot Products for 2007!* (Plus some older ones that are *still* hot!)

The dictionary defines a passel as "a fairly large group or amount." And that's exactly what we have at ***astronomics***, a passel, *nay,* a veritable plethora of scopes

The TMB 5.1" triplet apo is a *2007 Hot Product !*

TMB 130 triplet apo **$3790**

Tired of being on a multi-year waiting list for apo optics that never come? Here's a better idea. The **TMB Optical TMB-130** 130mm f/7 triplet apo – a *Sky & Telescope Hot Product for 2007* that's available now!

The superb TMB-130 *Signature Series* refractor uses the highest grade FPL-53 ED glass in its fully multicoated air-spaced triplet lens for a level of apochromatic color correction that impresses even its creator, renowned optics designer Thomas M. Back.

It has a collimatable temperature-compensated lens cell; a rotating 4" dual-speed rack and pinion focuser for medium format, 35mm, and CCD photography; 2" and 1.25" compression ring eyepiece holders; retractable lens shade; dust covers; and fitted hard case. It's available now and it's priced right!

Your car's back seat will hold a 16" Meade LightBridge.

Meade 16" f/4.5 LightBridge **$1999**

The **Meade LightBridge Dobsonians** – all of them named *Sky & Telescope Hot Products for 2007* – use a truss-tube design that lets you break down even the largest 16" model into a few small packages that fit comfortably into the back seat of most compact cars.

All Meade LightBridge Dobsonian reflectors have a smooth 2" machined aluminum Crayford-style focuser with a separate 1.25" eyepiece holder; a 2" 26mm QX eyepiece with a very wide 70° field of view, and an illuminated wide field non-magnifying red dot-type finder with four different reticle patterns.

Steel roller bearings in the base provide smooth hitch-free azimuth motion at the touch of a finger. Altitude tension is adjustable. A battery-operated fan on the metal primary mirror cell assures fast cooling of the diffraction-limited BK7 optical glass mirror. No tools are needed to assemble and break down each Meade LightBridge in the field.

The prices below include shipping from Meade.

8" f/6 LightBridge	**$599**
10" f/5 LightBridge	**799**
12" f/5 LightBridge	**999**
16" f/4.5 LightBridge	**1999**

You can put the sky in your pocket with this *Hot Product.*

$19.95

Sky & Telescope named this inexpensive 6" x 9" 110-page/84 chart **Pocket Sky Atlas** a *Hot Product for 2007.* They called it the atlas of choice "for naked eye or binocular observing . . . a favorite for anyone using a telescope with a red dot finder. One editor even reported hunting down more than 60 galaxies in the Virgo Cluster in an hour and a half using just one of the atlas's 84 charts."

Big chips are a-comin'. Their sales are in sight.

Some not-yet-on-the-market products were named *Hot Products for 2007* – **SBIG** and **Finger Lakes Instrumentation** CCD cameras using Kodak's new KAF-09000 and KAF-16803 imaging chips. According to *Sky & Tel,* these 9 and 16 megapixel "full-frame (as opposed to interline) chips use microlens technology to boost quantum efficiency, have lower noise, and now provide antiblooming protection. Best of all? Price. The new CCDs cost roughly one-third . . . making cameras with the new detectors, while still pricey, within range of many amateurs' budgets." When they ship, ***astronomics*** will have them.

Own a digital SLR camera? Here's a *Hot Product* just for you.

$39.95

The **AstroPix "Guide to Astrophotography with DSLR Cameras"** is a book on a CD-ROM and a *Hot Product for 2007.*

It tells you everything you need to know about taking astrophotos with a digital SLR, plus how to process the images after you shoot them, with step-by-step directions that produce beautiful results.

Burgess/TMB Planetary eyepieces – *2007 Hot Products!*

$99

The *Hot Product* **TMB Planetary** eyepieces at $99 may shake up your beliefs about how much you have to pay for a quality eyepiece from a famous designer.

They were created by noted optics designer Thomas M. Back to complement the performance of his state-of-the-art apochromatic refractors, like the new **TMB-130**, above. When you design premium apo scopes, you design eyepieces that get the most out of them. The 2.5, 3.2, 4, 5, 7, 8, and 9mm 1.25" long eye relief TMB eyepieces do just that, and they will get the most out of *your* scope, too.

The $69.95 Astro-Tech diagonal is a *2007 Hot Product,* but truth be told, these could *all* be called hot products.

$139.95

$149.95

$69.95

The **Astro-Tech *dielectric* 1.25" star diagonal** was named a *2007 Hot Product* by *Sky & Telescope.*

Like *all* the hot Astro-Tech diagonals, it has advanced 99% reflectivity *46-layer* dielectric coatings on its 1/10th wave BK7 optical glass substrate, plus a brass compression ring eyepiece holder that won't scratch the barrels of your costly eyepieces.

The 2" diagonals have either a 2" barrel for refractors or a threaded ring that connects to a Schmidt-Cassegrain rear cell, plus a separate non-marring compression ring adapter for 1.25" eyepieces.

The 2" *quartz* diagonals provide 1/10th wave peak-to-valley surface accuracy – *even after being coated* – and include a Zygo interferogram as proof of performance.

Here are the prices of the **Astro-Tech** *dielectric* diagonals that we stock:

1.25", *a Hot Product for 2007*	**$69.95**
2", with 1.25" adapter	**139.95**
2" SCT, with 1.25" adapter	**149.95**
2" quartz, with 1.25" adapter	**189.95**
2" quartz SCT, w/1.25" adapter	**199.95**

Go ahead. Give in to your urge to own a TeleVue *is*-Series *Hot Product.*

NP-127is **$6985**

Sky & Telescope said the TeleVue Nagler-Petzval refractors were "among the most highly rated" scopes they had ever tested when they named the entire **TeleVue is-Series (imaging system) refractors** *2007 Hot Products.* The is-series photo/visual apochromatic refractors have been reengineered for astrophotography. They have larger non-vignetting focusers with advanced features, a Focus-mate 6:1 ratio manual fine focus system, a photo accessory adapter, carrying case, and more.

TV-60is, 2.4" f/6 doublet	**$1695**
TV-102iis, 4" f/8.6 doublet	**2985**
NP-101is, 4" f/5.4 Nagler-Petzval	**3985**
NP-127is, 5" f/5.2 Nagler-Petzval	**6985**

Big chip CCD? Fast focal ratio reflector? A *Hot* Paracorr says "no" to coma in your pics.

Paracorr STL **$275**

This **TeleVue Paracorr** – a *Hot Product for 2007* – lets you use a big 35mm-size chip SBIG STL CCD camera on a fast focal ratio Newtonian reflector without seeing the coma that normally turns stars at the edges of the field into seagulls.

The Paracorr STL threads directly into the front cell of SBIG STL-series cameras and provides "pinpoint star images from simple Newtonian optics as fast as f/4."

It may be a 2006 *Hot Product,* but a TeleVue Dioptrx still eliminates eyeglasses when observing.

$98

Dioptrx astigmatism-correcting lenses attach to TeleVue eyepieces so you don't have to wear eyeglasses to observe.

They come in 0.25 diopter steps from 0.25 to 2.50 diopters, plus 3.00 and 3.50 diopters. Each precision-ground multi-coated optical glass lens works with TeleVue eyepieces only: 22, 40, 55mm Plössls; all Type 4 Naglers; 26, 31mm Type 5 Naglers; 22, 27, 35, 41mm Panoptics; and Radians.

Hot product solar observing for the cost of an eyepiece!

$499

For less than cost of some premium eyepieces, the sub-Ångstrom hydrogen alpha filter in the **Coronado PST** (Personal Solar Telescope) lets you see the ever-changing drama of solar flares and prominences growing and subsiding before your eyes. The PST was a 2005 *Hot Product* and it's still a best-seller today.

The PST includes a dedicated 40mm refractor, built-in solar filter, a safe built-in Sun finder, and a 20x eyepiece.

Hot in December. Still hot today.

$399

One of the hardest gifts to find last December was the **Celestron SkyScout**. This *Hot Product for 2007* is still in short supply, but you'll be able to get yours before warm spring weather gets here.

This GPS-based non-magnifying hand-held personal planetarium locates more than 6,000 celestial objects visible to your unaided eye. Earbuds tell you about each object, or you can read the scrolling 5-line text/graphics display.

The Celestron SkyScout makes the night sky as familiar to you as your own back yard. Your whole family will love it.

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Meade 10" f/8 RCX400 **$5599** *freight paid*

This Meade *2006 Hot Product* gives "Ritchey-Chrétien-like" performance . . . at only a fraction the cost of a true R-C.

In 2006, *Sky & Telescope* said the new Meade RCX400 f/8 catadioptric "does indeed perform like a Ritchey-Chrétien," and named it a *Hot Product* for 2006. *Astronomy* also said it "delivers Ritchey-Chrétien-like performance at a fraction the cost."

Why pay $14,000 to $34,000 for the flat field of a true Ritchey-Chrétien reflector optical tube only – and still have to pay for a mount? Get the catadioptric that reviewers call "Ritchey-Chrétien-like" in a complete scope/go-to mount combo starting at $5599!

Here are the *freight-paid* prices on the Meade RCX400 f/8 go-to catadioptrics:

10" RCX400, with UHTC optics **$5599**
12" RCX400, with UHTC optics **6999**
14" RCX400, with UHTC optics **9599**
16" RCX400, with UHTC optics **16,999**

Meade LX200R scopes use an f/10 version of the RCX400 f/8 optics, and a few less bells and whistles, to make R-C-like performance even more affordable.

Here are the *freight-paid* prices on the Meade LX200R f/10 go-to catadioptrics:

8" LX200R, with UHTC optics **$2699**
10" LX200R, with UHTC optics **3699**
12" LX200R, with UHTC optics **4699**
14" LX200R, with UHTC optics **6499**
16" LX200R, without mount, w/UHTC **11,529**
16" LX200R, tripod, w/UHTC **12,999**
16" LX200R, altaz pier, w/UHTC **12,524**
16" LX200R, eq pier, w/UHTC **12,779**

In 1979, a coffee cost 25¢ and a Celestron 8 cost $1295. Today, $1399 buys an even better *go-to* Celestron 8 with *Hot Product SkyAlign* technology.

Celestron NexStar 5SE 5" Schmidt-Cassegrain **$799**

As for the price of coffee, you practically have to mortgage your house to pay for a cup at Starbucks.

A state-of-the-art 1979 C8 would cost $3667.08 in today's inflated dollars – but it wouldn't have a *SkyAlign* go-to computer, multicoatings, a DC drive, or a Plössl eyepiece like today's $1399 **Celestron NexStar 8 SE.**

But it *would* still have Celestron's superb Schmidt-Cassegrain optics, however. That's one advantage that hasn't changed over the years.

Unlike coffee and gasoline and all the other little necessities of life, the cost of a Celestron has actually *deflated* over the years. You get more, but you pay less.

Its no-guesswork *SkyAlign* go-to computer finds sky objects for you automatically to make astronomy easy as 1-2-3. *SkyAlign* was named a *Sky & Telescope Hot product for 2006.* Starbright XLT multicoatings give you brighter images. These are just two of the many features on the **NexStar SE** scopes that were unavailable at *any* price only a few short years ago.

The **Celestron NexStar SE** telescopes. Great values? *Yes!* Here are the models we stock:

NexStar 4 SE, 4" Maksutov **$599**
NexStar 5 SE, 5" SCT **799**
NexStar 6 SE, 6" SCT **999**
NexStar 8 SE, 8" SCT **1399**

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Meade Deep Sky Imager Pro, $399, a *2006 Hot Product.*

The **Meade Deep Sky Imager Pro** in 2006, and the original $299 single shot color **Deep Sky Imager** in 2005, were both *Hot Products.* The more sensitive DSI Pro takes monochrome astrophotos for only $399 – a fraction the cost of a conventional CCD camera.

Buy the camera and color filter package shown here for $499 (that's a savings of $99 over the cost of buying the camera and filters separately) and the DSI Pro takes gorgeous tri-color images as well.

It works with any telescope, but you can use its NASA-developed "Drizzle" software with Meade Autostar-equipped ETX, LX90, LX200, or RCX400 scopes to take images *up to 4.9 megapixels in size.*

Some think the Telrad is a *Hot Product* every year.

$39.95 Telrad, including batteries

We don't know if the original **Telrad** bull's-eye non-magnifying finder was ever named a *Hot Product.* If it wasn't, it deserves to be. It's not just a finder. It's an icon.

The Telrad seems to project circles of red light on the dome of the sky that make it easy to aim your telescope or to star hop from object to object. We've sold literally thousands of Telrads over the years. It's one of our best-sellers. Isn't it time you had a Telrad of your very own?

I just wanted to let everyone know what excellent customer service I received from Ken. He went several extra steps to get an item I ordered shipped to my location in Iraq. For any who ask me on my recommendations on a store, Astronomics will be my only answer. Great customer service all the way through.

Customer Quote of the Month #180

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Astro-Tech. The little telescopes that could.

The image below was taken through the $329 66mm **Astro-Tech AT66ED** refractor. You'll find the full size, full color version on our **www.astronomics.com** website. Just enter "AT66" in the quick search box to get to the scope and click on the links in the scope copy to get to the original 20" tall full color image.

While you have that image open, open another web browser, go to Google images and enter "NGC7000" in the search box. Compare the image taken through the $329 Astro-Tech AT66 to any of the hundreds of North American Nebula images shown on Google. Then ask yourself, "Who needs a $6700 refractor, 300mm reflector, or any of the other big and expensive scopes that took the other astrophotos on Google when I can get images as good as the Astro-Tech AT66 can take for only $329?"

$329
Astro-Tech AT66ED, in brass, chrome, black, blue, green, red, burnt orange, or white

The **Astro-Tech AT66ED** has superb 66mm f/6 ED optics, rotating dual-speed Crayford focuser, your choice of eight tube colors, and a hard carrying case. It's an amazing value at only $329!

And if the 66mm AT66ED can take images like this, imagine what you can do with the new **Astro-Tech AT90EDT** 90mm f/6.7 ED *triplet* apochromat at $1295!

AT90EDT **$1295**

The three-lens AT90EDT uses genuine FPL-53 ED glass for high-contrast, color-free images (most scopes in its size and price range use less-expensive FPL-51). And bigger scopes are on the way!

Photo courtesy Sean Walker; Astro-Tech AT-66; SBIG STL-11000

An SBIG camera took the picture above.

$1395 SBIG ST-402XME

Sure, it was one of the big SBIG CCD cameras on that $329 Astro-Tech scope, but you don't have to buy a big SBIG to get SBIG quality and ease of operation.

The **SBIG ST-402XME** shown has the bells and whistles of a big SBIG camera, but a smaller price.

Its advanced *microlens* CCD imaging chip uses a tiny lens over each pixel to focus the light and increase sensitivity. The chip has a 765 x 510 array of 9 micron pixels with no column defects, high speed USB electronics, thermoelectric cooling with a built-in whisper fan, and more.

The monochrome version is only $1395. With an internal color filter wheel, it's $1595. Either way, you get great images and SBIG's traditional ease of operation at a very attractive price.

Quality SBIG CCD cameras are priced from $1395 to $12,995.

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Price match fine print: competitor's price must be verifiable and available nationally; chain store, close-out, and going-out-of-business prices are excluded; no retroactive price matching; a package price must be from a single competitor.

Add one of these filters to your observing kit, and you'll see the Sun in a whole new light. /// **BY ROD POMMIER**

How to choose a Hydrogen-alpha filter

Only one star, the Sun, lies close

enough to resolve through amateur telescopes. Observing the Sun provides a superb daytime activity for novice astronomers, even those living in light-polluted cities. Most amateurs look at the Sun using white-light solar filters. More and more observers, however, are selecting Hydrogen-alpha (Hα) filters, which highlight the Sun's chromosphere. With recent advances in technology and subsequent price drops, one of these filters may be right for you.

Four fine filters

I reviewed four Hα solar filters with a range of prices and bandpasses. I tested them in my home observatory in Portland, Oregon, on days when seeing was a 3 or 4, on a scale where 5 is excellent. Temperatures ranged from 32° F to 85° F (0° C to 30° C). I tested all the filters with a 14-inch Schmidt-Cassegrain telescope (SCT). I used a 77mm energy-rejection filter (ERF) at the front end of the telescope to reduce solar radiation before it strikes the main filter.

I also tested them with an 8-inch SCT using a 60mm ERF. Because it's a stand-alone unit, I tested the Coronado Instruments Personal Solar Telescope (PST) mounted piggyback on my 8-inch SCT.

Daytime is the right time

The DayStar 0.06 nanometer (nm) ATM filter requires electricity for its built-in heater, which keeps the filter's temperature in the desired range. A rheostat permits precise tuning by changing the filter's temperature. Coupling the filter to the telescope requires a T-adapter.

The view through the DayStar was astounding. The chromospheric network showed fine rice-grain detail during moments of good seeing. Filaments appeared considerably darker than the disk, while flares were bright, like hot embers glowing through the ashes in a campfire. Crimson prominences had sharply defined edges against a pitch-black sky. Prominences were dimmest through the DayStar, an effect of the narrower bandpass.

Personal solar observing

The PST is an Hα-filtered refractor that cannot be used for any other kind of observing. It has a 40mm aperture and a 400mm focal length, yielding f/10. The PST's etalon (interference filter) uses a central spacer to keep the filter's wafers at the required distance from each other. This design keeps the telescope tuned to the Hα line throughout a wide temperature range, so no electric heater is required. In addition

Rod Pommier *is an associate professor of surgery at Oregon Health and State University.*

CORONADO PST

Bandpass: less than 0.1nm
Aperture: 40mm
Focal length: 400mm
Price: $495
Contact info: Meade Instruments Corp., 6001 Oak Canyon, Irvine, CA, 92618
[t] 800.626.3233
[w] www.meade.com

ALL EQUIPMENT PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK

DAYSTAR Hα FILTER

Bandpass: 0.09nm to 0.03nm
Also requires: Energy-rejection filter (ERF)
Price: Filters range from $1,625 to $9,000; ERFs range from $160 to $660
Contact info: DayStar Filters LLC, 149 Northeast OO Highway, Warrensburg, MO, 64093
[t] 660.747.2100
[w] www.daystarfilters.com

THE SUN in Hα looks reddish. GREG PIEPOL

THOUSAND OAKS Hα PROMINENCE FILTER

Bandpass: 0.09nm
Price: Complete filter kits range from $630 to $950
Contact info: Thousand Oaks Optical, Box 4813, Thousand Oaks, CA, 93012
[t] 805.491.3642
[w] www.thousandoaksoptical.com

Thousand Oaks Hα filter

Thousand Oaks ERF

to the focusing knob, a knurled knob allows fine tuning of the etalon, but it rarely needs adjustment for routine use.

The PST has no mount and must be attached to a camera tripod or mounted piggyback on a larger telescope. It comes with a 20mm Kellner eyepiece and a built-in Sol Ranger solar finder. A pinhole, white-light solar image projects onto a translucent white disk when the Sun is centered in the PST.

The Sun's image through the PST occupied only about half the field of view. The background sky was dark red-brown, but the PST still provided good contrast for prominences. I used a 12mm Plössl eyepiece for closer views of prominences. Filaments were dark and stood out nicely against the solar disk. The chromospheric network was visible as a mottled or eggshell texture on the disk, but it lacked rice-grain detail seen through the DayStar filter.

The PST's convenience is a big plus. Anytime the Sun poked its face through breaks in Oregon's cloudy skies, I could observe it through the PST in a matter of seconds. This was more practical than having to connect an ERF, adapters, and an Hα filter to a telescope recently used for nighttime observing.

Grand solar views

The Thousand Oaks filter requires a telescope at f/15 or slower once its ERF has been attached. (Divide your telescope's focal length by the ERF's aperture).

This Hα filter is a compact 4.75" by 2" tube with a plastic tuning screw that turns a tilting mechanism. The 0.09nm bandpass provided views similar to that through the PST, but the Thousand Oaks filter had some advantages. The larger aperture provided better resolution of the chromospheric network's texture during moments of good seeing. Prominences were noticeably brighter than through the DayStar. Any dimming of the prominences seemed compensated by an equivalent darkening of the background sky, which was dark red-brown. As I increased the magnification, the prominences retained good detail.

Focus on prominences

Lumicon markets its 0.15nm bandpass system as a Solar Prominence Filter, but it can show filaments at times. It requires a telescope that will be at least f/20 with the ERF applied. One side of the disk-shaped filter has a tube that slides into a 2" focuser. The other side has an adapter for 1¼" eyepieces. The unit has a screw that turns a tilting mechanism to tune the filter to the Hα line.

I saw no hint of the chromospheric network through the Lumicon filter. However, I could see large filaments faintly against the solar disk. Prominences were best through this filter, appearing as bright red features projected against a reddish-brown background. Although contrast between prominences and the sky was less than through the other filters, prominences looked best through the Lumicon filter.

Pick a winner

The best Hα filter for you depends on your goals and budget. If you can afford spending a few thousand dollars and you are serious about Hα solar work, then your first choice should be the DayStar 0.06nm ATM filter. It shows the most surface detail and shows prominences well at the same time.

If you can afford about a thousand dollars and are serious about Hα work, the Thousand Oaks filter is a good choice. It provides bright views of prominences and full-disk views with lots of surface detail.

If your budget is smaller and you are mostly interested in observing solar prominences, then the Lumicon filter is perfect for you. It will show every prominence the expensive filters will.

If your budget is a few hundred dollars, then consider a PST. This dedicated Hα telescope is portable, practically foolproof, and works right out of the case. This scope will bring Hα observing within reach of many amateurs, and that makes it a valuable product.

If your first look through a telescope was memorable, get ready to experience that feeling the first time you see the Sun through one of these Hα filters. As you do, you'll need to budget more time in your life for observing, because you'll be busy both day and night.

ONLINE EXTRA For more on Hα filters, go to www.astronomy.com/toc.

LUMICON Hα PROMINENCE FILTER

Bandpass: 0.15nm
Price: Complete filter kits range from $699 to $899
Contact info: Lumicon International, 750 E. Easy Street, Simi Valley, CA, 93065
[t] 805.520.0047 [w] www.lumicon.com

Lumicon ERF

Lumicon Solar Prominence filter

ASK ASTRO

Astronomy's editors and experts from around the globe answer your questions about the cosmos. This month: where the Big Bang happened, education for astronomers, and celestial coordinates explained.

BIG BANG

Q: Where in space did the Big Bang happen? — BRIAN McDONALD, WALTON BEACH, FLORIDA

A: At the time of the Big Bang, some 13.7 billion years ago, the entire universe was concentrated in a single point. This point had an extremely small size — much smaller than the size of any known particle — and an incredibly high density and temperature. The term "Big Bang" actually refers to the moment when the universe started expanding, as opposed to some kind of explosion as the event's name implies.

Each part of the universe we see today originated from the initial point where the Big Bang happened and expansion began. This is why we say **the Big Bang happened everywhere.** Since the Big Bang occurred, the initial point in space has expanded into the star- and galaxy-filled universe we know today and cooled to a temperature of 2.73 degrees above absolute zero (–454° Fahrenheit [–270° Celsius]).

— **DRAGAN HUTERER,** KAVLI INSTITUTE FOR COSMOLOGICAL PHYSICS, UNIVERSITY OF CHICAGO

AN ASTRONOMER'S EDUCATION

Q: What kind of education does a person need to become an astronomer? — KIM LEWIS, NEWBURY PARK, CALIFORNIA

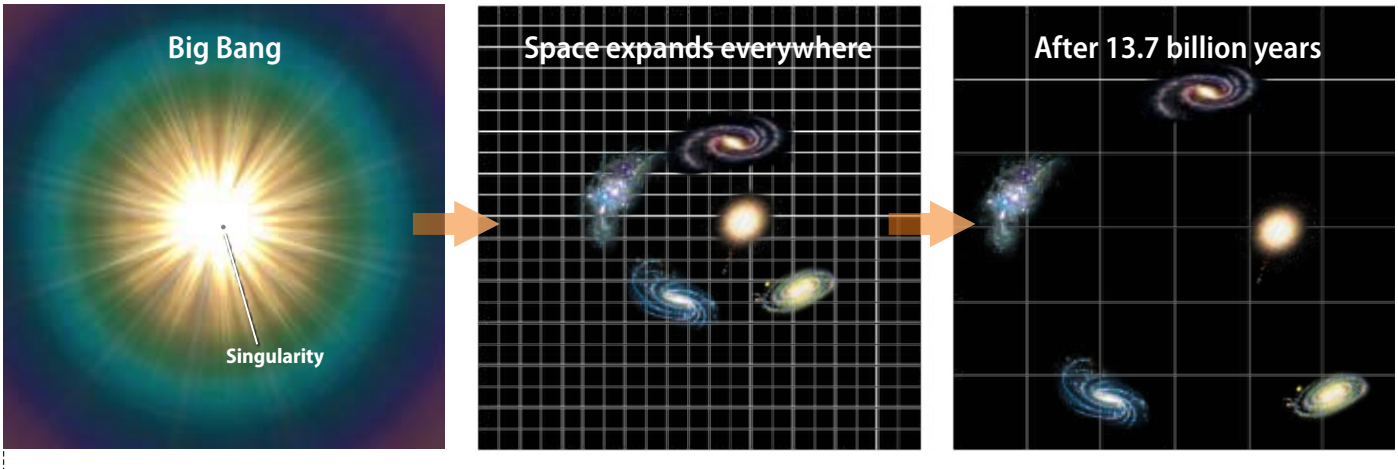
A: The most important thing is to get a firm foundation in basic science and math. This means taking high-school physics and chemistry courses. In college, take classes at as high a level as you can handle, and fit in all the math you can. The typical astronomy student won't take specialized courses, like stellar evolution or cosmology, until he or she finishes building this basic foundation.

Future astronomers should also plan on honing their computer skills. If you're interested in observational astronomy, my sense is that the future will involve more computational work than it has up until now. Computer-programming skills allow astronomers to create computer simulations. Take computer-programming courses to get a leg up in your astronomy career. The ability to construct and navigate large databases will also be important.

Four years of college and a bachelor's degree in physics, astronomy, or math will help prepare students who plan to do astronomical research. Teaching physics or astronomy at the high-school level requires at least a bachelor's degree and a teaching certificate. Teaching at a community college requires at least a master's degree. Nearly all university professors hold a Ph.D.

Depending on the field of astronomy you decide to pursue, more specialized academic work leading to a career as a professional astronomer typically starts in graduate school.

Many professional astronomers complete a Ph.D. program in astronomy or physics. Specialized fields include astrophysics, geophysics, astrobiology, planetary science, planetary atmospheres, and cosmology, just to name a few. The programs available are as various as the universities that offer them. Astronomers with doctorates can opt to do astronomical research, find university employment as professors, or split their time between research and teaching activities.



ASTRONOMY: ROEN KELLY

A SINGLE POINT contained the entire universe at the time of the Big Bang. This is why most cosmologists say the event, which ushered in the existence of space and time, happened everywhere. The moment the universe began expanding defines the Big Bang itself.

Astronomy jobs also exist for those with astronomical knowledge and know-how but no formal degree. Observatories, science centers, and nature centers often have positions available, like educational leader, for people who know their way around the sky. Some positions are paid, and some are unpaid. Check with your local observatory or science center to find out what's available. — **JAMES TREFIL,** CLARENCE J. ROBINSON PROFESSOR OF PHYSICS, GEORGE MASON UNIVERSITY

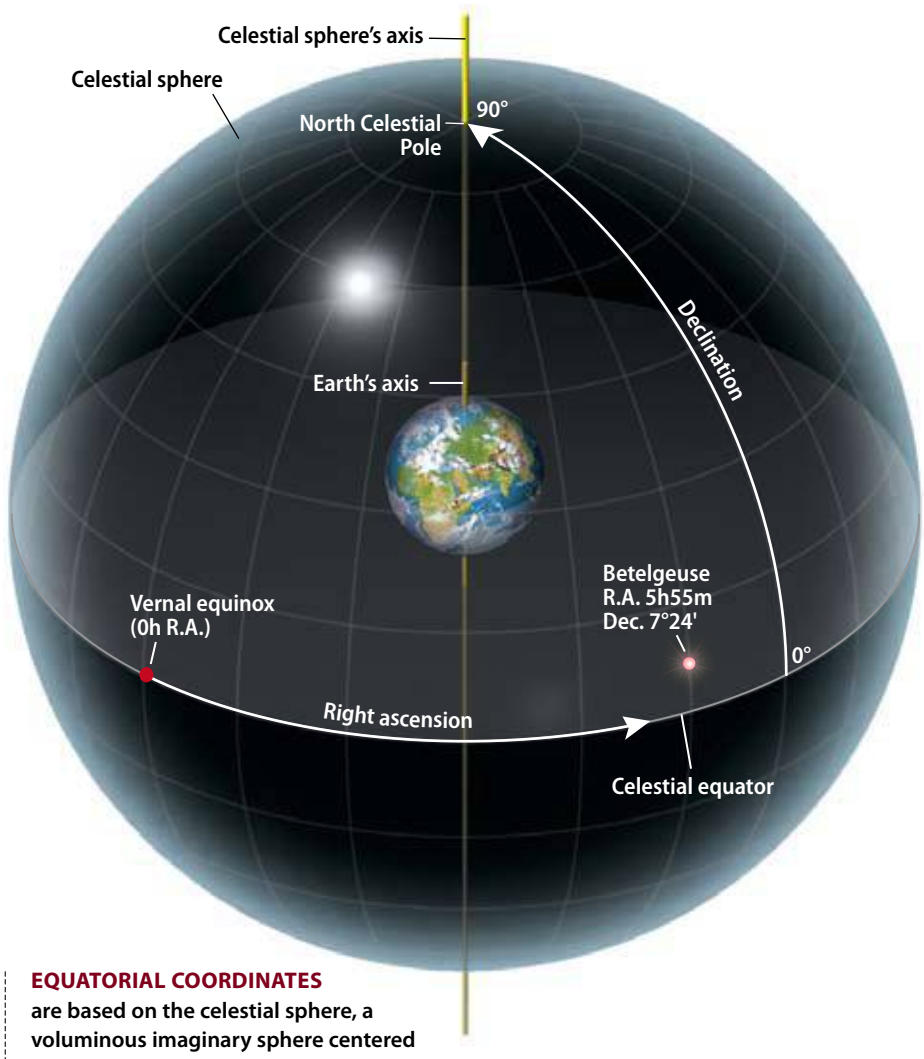
CELESTIAL COORDINATES

Q: Is there a simple way to explain the equatorial coordinate system so an amateur can understand it? — CHARLES MILLER, KEARNEY, MISSOURI

A: Many amateur astronomers have difficulty understanding the equatorial coordinate system at first. But once you get the hang of it, using it becomes as easy as using latitude and longitude to locate places on Earth. **Astronomers use the terms right ascension (R.A.) and declination (Dec.) to refer to an astronomical object's coordinates on the celestial sphere.** Right ascension is comparable to longitude. Longitude measures the angle east or west along Earth's equator, starting from an arbitrary zero point — the Prime Meridian that passes through Greenwich, England. Right ascension measures the angle from east to west along the celestial equator, starting from the arbitrary zero point of the vernal equinox — where the Sun crosses the celestial equator during the March equinox. R.A. is measured in hours, minutes, and seconds, with one hour equal to 15 degrees of arc.

Declination measures in degrees how far above or below the celestial equator an object lies. Polaris, which lies above Earth's North Pole, has a declination of 90°. An object located directly above Earth's South Pole would have a declination of –90°. Objects along the celestial equator (which is the projection of Earth's equator into the sky) have a declination of 0°. So, if you live in Chicago at a latitude of 42° north, an object passing directly overhead will have a declination of 42° north because it is 42° above the celestial (and Earth's) equator. — **LAURA LAYTON,** ASSOCIATE EDITOR

Understanding equatorial coordinates



EQUATORIAL COORDINATES are based on the celestial sphere, a voluminous imaginary sphere centered on Earth. *ASTRONOMY:* ROEN KELLY

IN THE KNOW

CELESTIAL SPHERE
An imaginary sphere centered on Earth; north and south celestial poles lie above Earth's north and south poles, and the celestial equator is a projection of Earth's.

PRIME MERIDIAN
A longitudinal line that runs from Earth's North Pole, passes through the Royal Observatory in Greenwich, England, and terminates at Earth's South Pole; marks 0° longitude.

COMING NEXT MONTH ...
How can the Sun's energy be measured? Post your comments about this question online at www.astronomy.com/forums.

Send your questions via e-mail to: askastro@astronomy.com; or write to: Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Amateur astronomers are finding more supernovae than ever before. Follow these tips and join the hunt. /// **TEXT AND IMAGES BY DOUG RICH**

How to search for supernovae

Columbus discovered America, but

you can find something even bigger — an exploding star! With greater frequency, dedicated amateurs are using better telescopes and CCD cameras to search for supernovae and discover them. Never has this goal been so easy to reach.

It's easy because telescope drives have superb pointing and tracking abilities — features necessary for supernova hunting. A CCD camera, coupled with a small or medium-aperture telescope, produces usable galaxy images in about a minute. Also, fast computers (for image acquisition) and excellent astronomy software lie within reach of most novice hunters.

The biggest challenge to finding your own supernova is the competition, which is intense. Automated supernova-search programs scan the heavens and take thousands of galaxy images every clear night. A small-telescope owner can still compete, however. The following strategies will prepare you so that when the final important element (luck) comes your way, you'll be ready.

Galaxy selection

Tens of thousands of galaxies lie within reach of a 12-inch telescope equipped with a CCD camera. So, which should you target? Some galaxies produce more exploding stars than others, and knowing which to monitor is critical to your success.

Unlike professional search teams that can take 1,500 pictures a night of all galaxy types, amateurs have to be more selective. Elliptical galaxies contain older stars and occasionally produce supernovae but not often enough to warrant a spot on the list. Lenticular and irregular galaxies also fail to deliver on a regular basis.

The action lies within spiral galaxies exhibiting active star-formation. Supernovae use up their nuclear fuel quickly and are still adolescents when they explode. You'll find them in the company of other young stars in spiral galaxies' arms.

A galaxy's distance is important. If the galaxy is too far away, you may miss a not-so-bright supernova. Because a galaxy's radial velocity (speed moving away from Earth) correlates to its distance, choosing a galaxy within a certain cutoff radial velocity is critical. I use a 12-inch scope, so I choose galaxies with recession velocities less than 11,000 km/sec. This means the galaxies on my target list lie less than 500 million light-years away. You can find information on a galaxy's type and radial velocity at the NASA/IPAC Extragalactic Database web site at nedwww.ipac.caltech.edu.

Another good place to look for target galaxies is the Third Reference Catalog of Bright Galaxies, or the RC3. This catalog contains more than 23,000 galaxies.

Browsing through the virtual sky with software is another way to find worthy candidates. Check with NED or the RC3 catalog to confirm the galaxies you include on your list are the correct type and distance. A reasonable number of target galaxies is 2,000 for an amateur who takes approximately 600 to 800 images per month.

With a 12-inch telescope plus a CCD camera, it takes about a minute to record stars down to magnitude 18. Spiral galaxies inside my distance cutoff usually produce supernovae of 18th magnitude or brighter.

THE AUTHOR stands next to his 12-inch Meade Schmidt-Cassegrain telescope, which sits upon a Software Bisque Paramount ME mount.

Equipment

As a rule, large CCD pixels are more sensitive than small ones. Matching a CCD camera's pixel size to the telescope's focal length is important for any application, but, for the supernova hunter, it is essential. If you use a camera that has large pixels together with a low-focal-ratio telescope, images will contain too much sky in each pixel. A supernova that sits close to a foreground star or bright nebula could go unnoticed.

Use a telescope with a focal length between 60 and 120 inches (1,500mm and 3,000mm). Such an instrument, coupled with a large-pixel CCD camera, produces

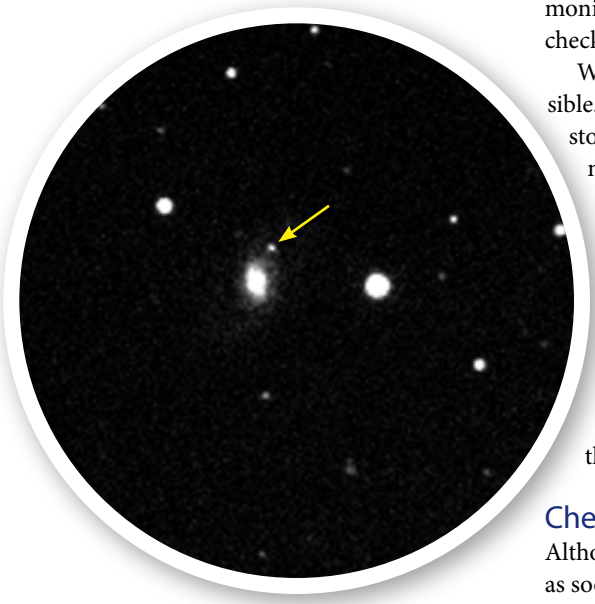
Doug Rich *is an avid deep-sky observer and supernova hunter. He resides in Hampden, Maine, with his wife Laurie.*

the magnification needed and yields pixel resolutions within the acceptable range of 1.5" to 3.5" of sky per pixel. I have kept this in mind with my search program. Using a Santa Barbara Instrument Group (SBIG) ST-9 CCD camera (20-micron pixel size) and a 12-inch Schmidt-Cassegrain telescope with a focal reducer, I work at a focal length of about 90 inches (2,300mm). This gives me a resolution of 1.8" per pixel.

Work as fast as you can. The more galaxies you capture on a given clear night, the better your chances of netting a discovery. This means taking unguided images with minimum exposure times. Taking unguided images puts huge demands on your mount — especially with long-focal-length telescopes.

SBIG offers a feature with its CCD cameras that compensates for poor telescope tracking. Using "Track and Accumulate," you can stack two 30-second exposures together to produce one 60-second image. Meade's DSI camera works in a similar way. Although these features may seem like lifesavers, they will definitely slow you down.

If you are fortunate enough to own a telescope whose mount points and tracks with great accuracy, you can use software that will automate your supernova search. Such software includes: Software Bisque's *TheSky 6*, *Orchestrate*, *CCDSoft*, and *T-Point*, and Cyanogen's *MaxIm DL* coupled with DC3's *ACP*.



THE AUTHOR'S SECOND confirmed discovery, now known as SN2003dw, came in April 2003. He found this supernova in UGC 10548, a barred spiral galaxy approximately 400 million light-years away.

Try keeping an electronic logbook to manage your search. I use *Deepsky2000*. Besides being a necessary reference for discovery reports, this program lets me see where I'm going and where I've been in terms of imaging my target galaxies. In other words, it lets me cycle through the sky systematically.

The hunt

Exactly how you patrol the sky is a matter of choice. Some hunters divide the heavens into wide east-to-west "chunks," and work slowly from north to south. This method favors the amateur using a fork-mounted telescope, which passes effortlessly through the meridian.

Another technique uses long, narrow slices of the sky, 15° to 30° wide. With this process, owners of German equatorial mounts can remain on either side of the meridian for extended periods of time with minimal crossings.

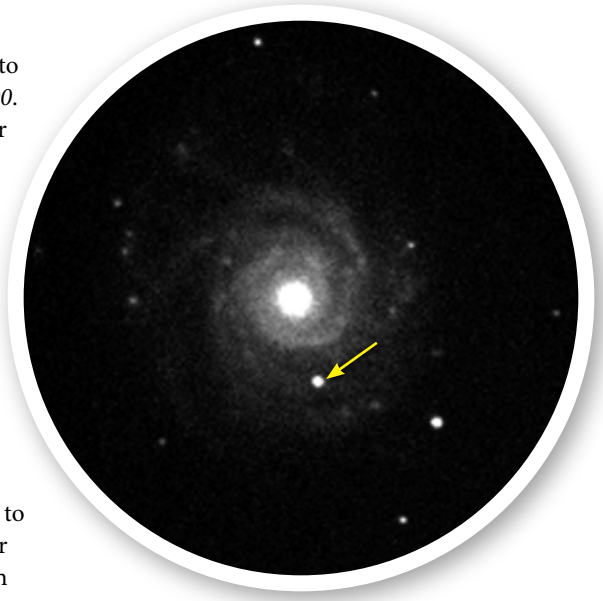
Another approach employs hunting by constellation. You just image all target galaxies in one constellation before moving on to the next constellation.

Whichever method you choose, stick with it. This ensures equal coverage of your selected galaxies. And remember, it's far more beneficial to sequence through a smaller number of galaxies often — finding a supernova soon after explosion — than to monitor a larger number of spirals you check less frequently.

Work on clear, moonless nights if possible. However, don't let a little moonlight stop you. If the air is dry enough, and if no haze exists, CCD technology lets you subtract moderate moonlight from an image. Here you may be able to get the edge on the competition because many hunters balk at taking photos in moonlight. My first confirmed discovery was on an evening with the Full Moon rising in the eastern sky. Get out and search as often as the weather permits.

Checking your images

Although you should look at your images as soon as possible, avoid the temptation of checking as you hunt. Inspecting the pictures immediately uses up valuable time. The more galaxies you download to your hard drive on a given night, the greater your chance of success.



THIS DISCOVERY occurred in March 2005. SN2005ay turned out to be a bright type II (core-collapse) supernova caught soon after explosion. The host galaxy, face-on spiral NGC 3938, lies about 50 million light-years away.

The best reference images are yours, taken with the same equipment you use for supernova patrolling. At the outset, your search program will have two purposes. First, you're looking for undiscovered supernovae. At the same time, you are building a reference library of galaxy images. Other references, such as the Palomar Digital Sky Survey, can be helpful as a secondary guide but can also lead to "false positives" because of differences in pixel resolution, aperture of the imaging telescope, and exposure times.

The most basic way to check images is to use *CCDSoft*, *MaxIm DL*, or the image-acquisition program that came with your camera. Scan both the new and reference photos on your computer screen carefully, and look for changes.

A less-grueling method of inspecting your images is to "blink" them. *CCDSoft* and *MaxIm DL* allow the blink/compare function as long as you download the images in the FITS file format.

When comparing a new image against an older archived one (with the same pixel resolution), the software aligns or matches both images exactly — one on top of the other — then switches back and forth between them at a rate you control. As the images blink, a point in one photo not present in the other becomes obvious. A supernova becomes a flashing beacon that immediately gets your attention.

How do these methods compare? When checking galaxies the "old-fashioned way," it took me several hours to inspect 80 images. By blinking, I can review the same number in about an hour.

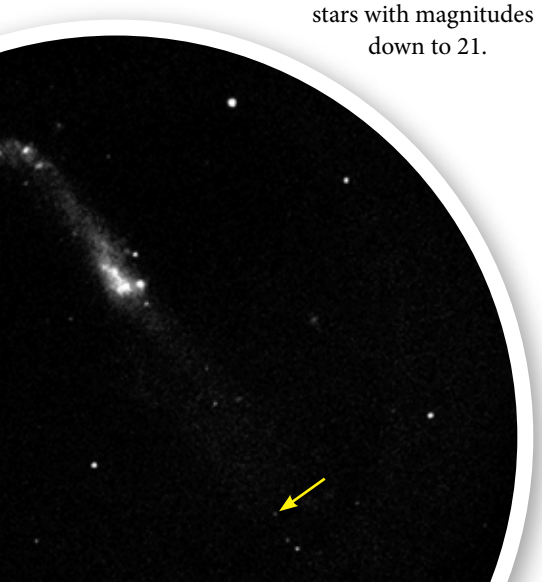
What to do if …

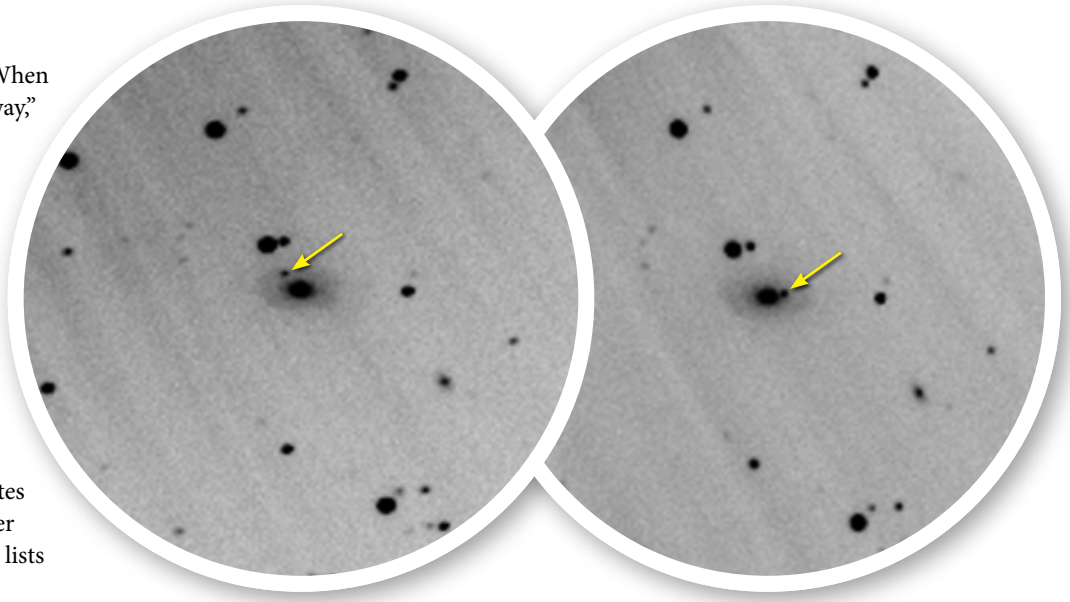
Objects you find embedded in or close to a galaxy's image could be new or known supernovae or one of a few other possibilities. First, check if the "suspect" has been bagged by another supernova hunter. Dave Bishop, an amateur astronomer, operates a supernova web page at www.rochesterastronomy.org/supernova.html, which lists new discoveries, including images.

The Central Bureau for Astronomical Telegrams (CBAT) maintains a "List of Recent Supernovae" page (cfa-www.harvard.edu/iau/cbet/000600/CBET000659.txt). Although these sites are updated regularly, it may take hours, or even a day, before new information appears.

CBAT makes an official announcement of a supernova discovery by electronic means with a Central Bureau Electronic Telegram (CBET) and later an *International Astronomical Union Circular* (IAUC). Access to CBETs and IAUCs is available to Internet users for $72 per year. Find subscription information at the CBAT web site.

If your suspect is not a known supernova, it could be camera noise, an asteroid in the same field of view as your target, or even a Milky Way variable star along the same line of sight. A second image on the next night will eliminate the first two possibilities, but the frame may still show the variable, which may be in the outburst or the bright phase of its period. In some cases, the Palomar Digital Sky Survey can be helpful for spotting variable stars with magnitudes down to 21.





THESE IMAGES show asteroid 12675 (Chabot) passing from east to west in front of galaxy IC 2193 in Gemini. These frames, taken 70 minutes apart, point out how easily an asteroid can be mistaken for a supernova. Also visible is the scattered light from nearby Castor (Alpha [α] Geminorum), which sits just outside the field of view to the northeast.

If the new star in your image has not been reported and is not camera noise, an asteroid, or (to the best of your knowledge) a variable star, then congratulations — you probably have discovered a supernova!

Unless you are an experienced supernova hunter already known by CBAT, you'll need a confirmation image taken by a veteran discoverer or professional astronomer. CBAT prefers the confirmation image be taken on the night after the discovery image. Establish contact with credible verifiers before discovery time.

Sending the discovery report

If professional astronomers are to observe the rapidly changing features of a new, still-brightening supernova, they need to be informed promptly. This is Daniel Green's job as director of CBAT. He is responsible for quickly getting the word out. When Green receives a discovery e-mail from an amateur, he makes a judgment call. Is this information reliable? Unfortunately, many reports turn out to be erroneous.

CBAT's web site covers items required for the discovery report. Also, with access to CBETs and IAUCs, you can study the content and format used by other discoverers. It's important to have the correct content and proper format in your report.

The three essential measurements you need for the discovery report are: the exact position of your supernova (astrometry), an estimate of its brightness (photometry), and its offsets from the parent galaxy. Herb Raab, an Austrian astronomer, has developed a software tool for pinpointing a supernova's location called *Astrometrica*. *CCDSoft*, *MaxIm DL*, and Santa Barbara's *CCDOPS* are some of the programs available for doing photometry.

Before you send your report to CBAT, remember to set your e-mail browser to the ASCII format (not HTML) and to limit each line to about 60 characters with a hard return after each line.

The right stuff

Besides the proper equipment and a list of well-chosen galaxies, the amateur supernova hunter also needs the right attitude to weather storms of disappointment and frustration. You'll probably end up taking hundreds, or maybe thousands, of pictures before you find your first supernova.

Look at it this way: The cataclysmic explosion of a star with your name on it already has happened somewhere in the universe. After traveling through space for millions of years, light from this rare event expectantly waits for you, the messenger, to announce its arrival. Then you've not only made history, you've looked at it!

SOMETIMES, you can mistake a Milky Way variable star for a supernova. In this case, the author captured an apparent outburst of a luminous blue variable star (not a supernova) in the Hockey Stick Galaxy (NGC 4656), which lies about 30 million light-years from Earth.

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Online astronomy groups let amateurs discuss observing, equipment, and the day's hottest issues. /// **PHIL HARRINGTON**

Attend an Internet star party

In the last 50 years, two innovations

have dramatically changed amateur astronomy. The first occurred with the widespread availability of inexpensive, but well-made, telescopes to consumers. The second was the Internet. For stargazers, the web represents anything from a club to a star party to a telescope. However, the greatest web-based innovations for astronomy have been discussion groups. On these sites, surfers around the globe gather at all hours of the day to showcase recent deep-sky images, share equipment advice, and debate the origins of the universe.

Some of these forums are restricted and focus on specific subjects, while others are free-for-alls where no astronomy subject is off-topic. Many people visit discussion groups because there are countless years of astronomical experience among the memberships. These sites are reliable resources for those new to astronomy.

Just like choosing a telescope or eyepiece, it's hard to know where to begin. So many online groups exist. To save you from searching throughout the web, here are a few popular online communities that host lively astronomy discussions.

There's no place like home

What better place to start than right here at *Astronomy*'s web site? Astronomy.com hosts a message board on many astronomical topics at www.astronomy.com/forums. Jeremy McGovern, assistant editor of *Astronomy*, manages the message board and believes the discussion board's strength rests with its knowledgeable and helpful members. "If you are headed out to the field to navigate an unfamiliar region of the sky or want to try digital imaging, you can post a question and have multiple answers from experts within minutes," he says.

In addition to their knowledge of the hobby, Astronomy.com members operate with great immediacy. "Some visitors will post their astro shots not long after imaging," explains McGovern. "If cloudy skies blocked your view of an occultation, chances are a forums visitor will post an image showing what you missed."

Looking to buy your first telescope? Post a question under the "Equipment" category, and you'll get great advice.

Something for everyone

For the largest collection of online discussion groups, head over to Yahoo! Groups at groups.yahoo.com. Typing "astronomy" into the search field will produce a roster of more than 1,300 groups segregated into categories, such as "Astrophotography," "Deep Sky," and "Planets." Clicking on any topic generates the related forums that share this subject. You name it, and someone probably has started a Yahoo! Group to discuss it.

One of the most popular Yahoo! astronomy groups is "Talking Telescopes," which I founded in 1999. What started out as a modest extension of my book *Star Ware* has since grown into an international gathering of nearly 7,000 stargazers. Members range from rank beginners to veterans with more than 40 years of experience. We all learn from one another.

Do you already own a scope and want to share your experiences with others? Talking Telescopes lets you share tips for getting the most from your instrument. Many members also belong to forums devoted to a particular telescope design, from big Dobsonians to refractors to Maksutovs.

Many Yahoo! Groups concentrate on specific equipment brands or models. Some of the more popular groups focus on

---

Phil Harrington *is online almost every day, usually hanging out on message boards at Talking Telescopes or Astronomy.com. Visit his web site, www.philharrington.net.*

Places to find or start astronomy conversations:

ASTRONOMY.COM
www.astronomy.com/forums

ASTRONOMYDAILY
forums.astronomydaily.com

ASTROMART
www.astromart.com/forums

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SCI.ASTRO.AMATEUR
Go to groups.google.com and enter "sci.astro.amateur"

TALKING TELESCOPES
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ONLINE ASTRONOMY GROUPS can scratch your astronomy itch. Check out various astronomy web sites for endless discussions on observing, cosmology, space-science missions, and thousands of other topics. *ASTRONOMY*: JAMES FORBES/ESO/VIRGO CONSORTIUM/NASA/STScI/ACS/ESA

Celestron NexStar instruments, Meade LX90 and LX200GPS telescopes, Orion SkyQuest reflectors, and Tele Vue products. Owners gather to share both successes and problems with their equipment, often coming up with fixes and work-arounds that the manufacturer may have missed.

The best of the rest

Other popular forums can be found at www.astromart.com, www.astronomydaily.com, and www.cloudynights.com.

These message boards host frank discussions, both pro and con, of astronomical equipment. Some people frequent all topics, while others seem content to find a comfortable niche and stay put.

All of these forums are moderated to varied degrees. This means all posted messages are permitted provided they cover astronomical topics and meet certain acceptable social norms for language and content. Forum moderators usually weed out unwanted or inappropriate messages, making for a friendly environment. This is not to say people can't disagree, but disagreements must be kept civil.

Rock-em sock-em discussions

If you're looking for a no-holds-barred exchange, then you should venture into the realm of Usenet newsgroups. These unmoderated, subscriber-based forums offer the greatest freedom in terms of message content, but some people will post notes that inevitably offend others.

By far, the most popular newsgroup for amateur astronomers is sci.astro.amateur. A recent survey of topics there showed everything from observing debates to political rhetoric, as well as a few less tasteful subjects. With Usenet newsgroups, you quickly learn to take the good with the bad.

Other newsgroups include sci.astro, sci.astro.ccd-imaging, sci.astro.hubble, sci.astro.planetarium, sci.astro.research, sci.astro.satellites.visual-observe, and sci.astro.seti. All are accessible through your e-mail program or web-based readers. Many people prefer to use the latter method, with the search engine Google.com offering an especially user-friendly interface.

Wherever you decide to venture in cyberspace, the important thing is just to get started. It's a lot of fun to explore astronomy discussions online — especially when clouds block your "real-space" view.

ONLINE EXTRA Read about Internet Relay Chat at www.astronomy.com/toc.

EQUIPMENT REVIEW

This new 6-inch telescope offers high-quality Schmidt-Cassegrain optics in a portable package. /// **BY PHIL HARRINGTON**

Celestron's new Schmidt-Cassegrain

Celestron has introduced a new model

to its Schmidt-Cassegrain line of telescopes — the C6, and it's Celestron's most portable one yet. This scope offers a 6-inch aperture and operates at f/10. Family resemblance is unmistakable. The C6 has a sleek black aluminum tube with the company's name and logo emblazoned in orange across its side.

Consumers may choose from four variants. For those who already own a telescope mount, the C6 is available as an optical-tube-assembly only. The least expensive complete C6 package, designated the C6-S, combines the telescope with Celestron's Advanced Series CG-5 German equatorial mount. The same C6 also is sold with the computerized version of the CG-5 as the C6-SGT. Finally, Celestron added the C6 to its lineup of single-support-arm NexStar Special Edition instruments. The NexStar 6SE, however, features an orange tube rather than black.

All varieties of the C6 come with a 25mm E-Lux Plössl eyepiece (60x) and a 1¼" prism star diagonal. A 6x30 finder scope is also included with each, except for the NexStar 6SE, which has a one-power red-dot finder instead.

Celestron coats all C6 primary and secondary mirrors with enhanced coatings for better reflectivity and less scattered light. Peak reflectance is 95 percent at a wavelength of 510 nanometers, with an average reflectance of 93 percent across the visible spectrum.

The corrector plate is ground from water-white float glass and then layered with the company's proprietary StarBright XLT anti-reflection optical coatings for improved light throughput. These coatings

THE C6 is Celestron's newest Schmidt-Cassegrain telescope. Its tube measures 16 inches long and weighs 9 pounds. Both the orange dovetail mounting bar and 6x30 finder scope are included. ALL PHOTOS: *ASTRONOMY*: WILLIAM ZUBACK; STAR CHART: *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY

/// SPECIFICATIONS

CELESTRON C6

Type: Schmidt-Cassegrain telescope
Aperture: 6 inches (150mm)
Focal ratio: f/10
Focal length: 1,500mm
Length: 16 inches (406mm)
Weight: 9 pounds (4.1 kg)
Included: StarBright XLT coatings, 6x30 finder scope, 1¼" prism star diagonal, CG-5 dovetail mounting bar
Price: $588

Contact information:
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Torrance, CA 90503
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[w] www.Celestron.com

Phil Harrington *loves telescopes of all types. The 4th edition of his telescope-review book,* Star Ware, *is now on sale.*

CELESTRON coats all optical surfaces with its StarBright XLT high-transmission, anti-reflection coatings for improved light throughput.

The C6's tailpiece accepts 1¼" accessories. A rubber-coated focus knob adjusts the telescope's primary mirror.

reflect less than 0.5 percent of the light striking them. Just as I found in a previous test of Celestron's C8-SGT with the same coatings (*Astronomy*, August 2004), image brightness was excellent in the C6.

Apart from being smaller (an advantage if portability is high on your wish list), the C6 looks like the C8. A gold-anodized dovetail bar bridges the 16-inch-long tube. The bar attaches the scope to the mount.

Focus by turning a small rubber-coated knob that protrudes from the scope's back. Focus moves the primary mirror fore and aft along a track inside the tube. All telescopes that focus images in this manner suffer some degree of image shift caused by the mirror tilting slightly when focused. This makes the image "jump." Through the C6, however, image shift was negligible, perhaps 10" (arcseconds) at most.

Under the stars

I selected Jupiter as my first target. Images through the C6 proved impressive. Jupiter's atmosphere showed great detail. I clearly saw the Great Red Spot and even the shadow of one of Jupiter's moons transiting across the planet's face.

After enjoying Jupiter for a while, I moved on to several beautiful globular clusters: M13 in Hercules, M22 in Sagittarius, and M2 in Aquarius. All three showed good detail through the 25mm eyepiece.

Next, I resolved some challenging double stars, including the Epsilon (ε) Lyrae quartet, Delta (δ) Cygni, and Alpha (α) Piscium, at magnifications up to 300x with a 5mm eyepiece in place. Jupiter also held its own at that magnification, although, because of sky conditions, the view was better through a 10mm eyepiece (150x). Star-testing showed the optics to be smooth and well-figured; they produced nearly perfect images on either side of focus.

Celestron didn't leave imagers behind, either. The C6 accepts the same wide array of accessories used by other Schmidt-Cassegrain telescopes, which makes the C6 perfect for astrophotography.

Overall, Celestron's C6 struck me as the perfect telescope for anyone who needs a highly portable instrument yet still wants a large enough aperture to see the sky well. For a great little telescope at a great little price, look no further.

CELESTRON includes a 1¼" star diagonal and a 25mm Celestron E-Lux Plössl eyepiece (60x) with the C6.

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Join *Astronomy* magazine

and astronomers from around the world as we stand in awe under the pristine sky of the *Valle de la Luna* in Chile's Atacama Desert to celebrate the brilliance of the southern Milky Way, the Magellanic Clouds and Southern Cross.

August 11-19, 2007

The Atacama Desert and Chile's Giant Optical Telescopes expedition includes airfare, most meals and sightseeing, which features archaeological sites pre-dating Egypt, hot springs and geysers. A tasting tour of one of Chile's prestigious vineyards is also included.

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MARCH 4–6

The International Dark-Sky

Association looks to bridge the transition toward sustainable light planning and urban development at its 19th annual meeting, held in Tucson, Arizona. At this gathering, attendees can discover innovations in lighting design and discuss how to protect our night sky. ☎ 520.293.3198; 💻 www. darksky.org.

LIGHT POLLUTION is an increasing problem for urban skygazers, as this nighttime map shows. The International Dark-Sky Association looks to curb this problem with solution-based advice for municipalities. INTERNATIONAL DARK-SKY ASSOCIATION

FEBRUARY 24
Wagman Winterfest
Wagman Observatory, Deer Lakes Park, near Russelton, Pennsylvania. ☎ 412. 487.9363; 💻 www.3ap.org/winterfest.

MARCH 2
Far Out Friday
Adler Planetarium and Astronomy Museum, Chicago. ☎ 312.922.7827; 💻 www.adlerplanetarium.org.

MARCH 2–4
Workshop: Mid-Atlantic Mirror Making
Mallard Lodge, Smyrna, Delaware. ☎ 302. 653.9445; ✉ don.surles@verizon.net; 💻 www.delmarvastargazers.org.

MARCH 3
Triad StarFest (Tri Star)
Guilford Technical Community College, Jamestown, North Carolina. 💻 technet. gtcc.cc.nc.us/comserv/cline/tristar.htm.

MARCH 9
Planetarium show: Mars in Close-up
Mills Observatory, Balgay Park, Dundee, United Kingdom. ☎ 01382.435967; 💻 www.dundeecity.gov.uk/mills.

MARCH 12–16
Lunar and Planetary Science Conference
South Shore Resort and Conference Center, League City, Texas. *Astronomy* Senior Editor Richard Talcott will attend. ☎ 281.486.2143; 💻 www.lpi.usra.edu/meetings/lpsc2007/home.shtml.

MARCH 14–18
Kisatchie Star Party
Kisatchie National Forest, near Natchitoches, Louisiana. ☎ 225.644.8604; 💻 www.bro.lsu.edu/bras/kisatchie.html.

MARCH 16–18
Tennessee Spring Star Party
Fall Creek Falls State Park, near Pikeville, Tennessee. ✉ watkinslk@comcast.net; 💻 www.cumberlandastronomicalsociety.org.

MARCH 17
Planetarium show: Astrolabes and Astrology
Montgomery College, Silver Spring, Maryland. 💻 www.montgomerycollege.edu/departments/planet.

MARCH 17
Lecture: Women in Aviation and Space
Steven F. Udvar-Hazy Center, Chantilly, Virginia. 💻 www.nasm.si.edu/events.

MARCH 17–18
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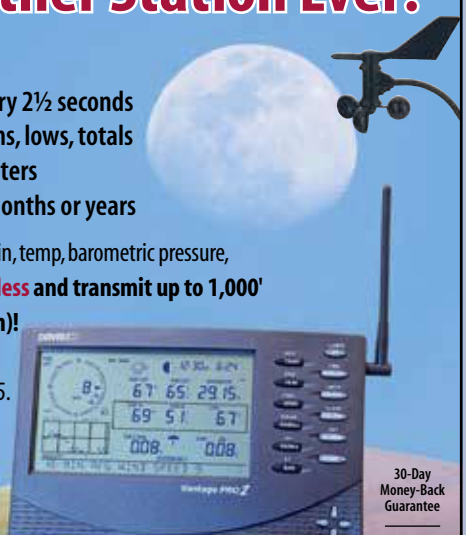
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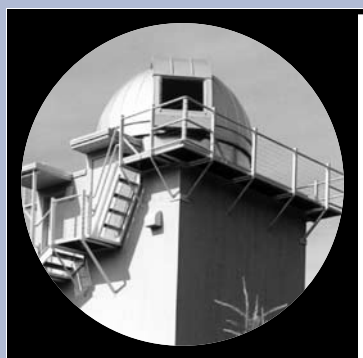

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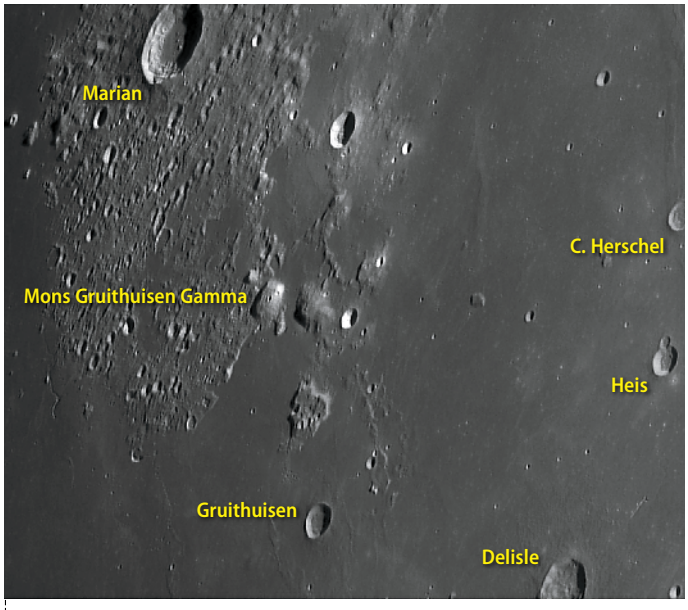
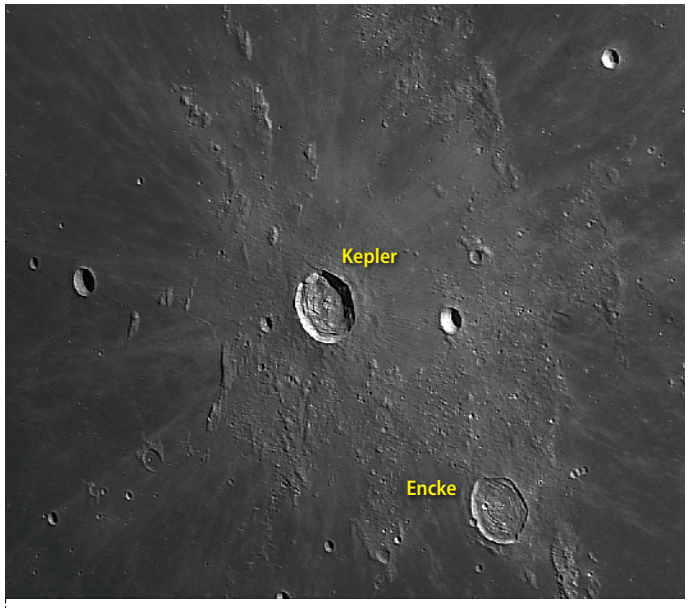
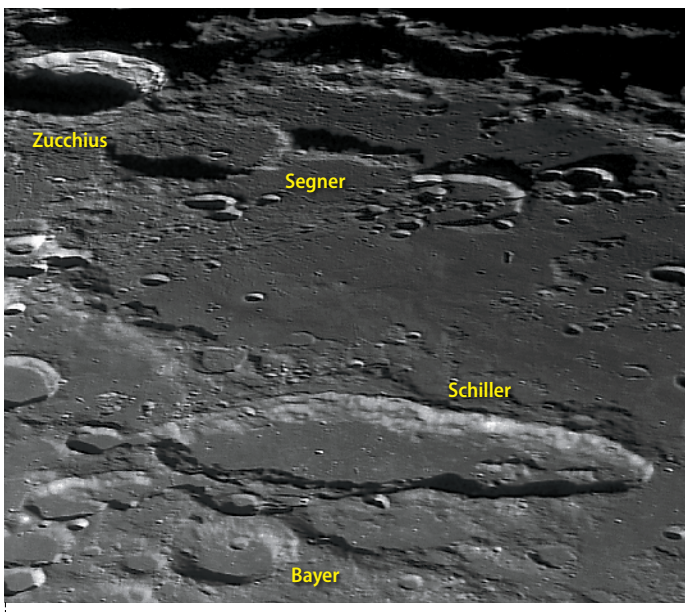


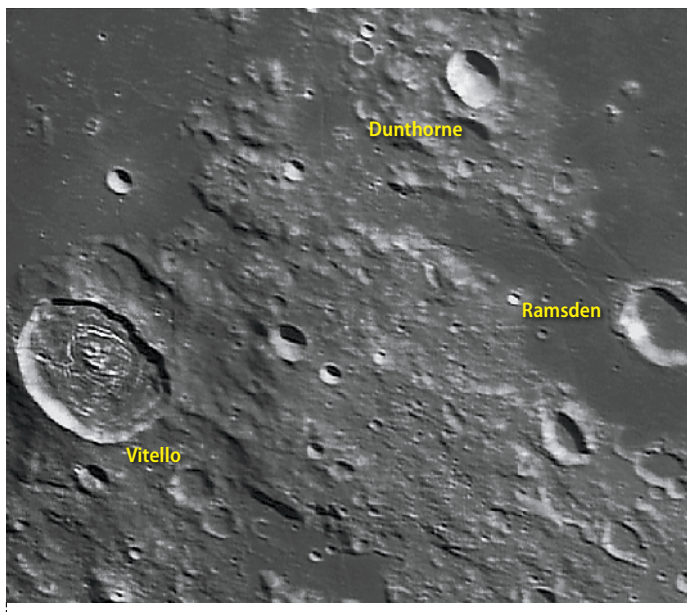
THE MOON'S Mons Gruithuisen Gamma, which is shaped like an upturned bathtub, is a tall, domelike mountain with a circular base. (12-inch Gladio 315 Lazzarotti Optics telescope at f/25, Lumenera Infinity 2–1 CCD camera, 0.055-second exposures, best 341 of 2,000 frames, taken April 10, 2006, at 16h05m UT, from Bangkok, Thailand) /// **PAOLO LAZZAROTTI AND TIZIANO OLIVETTI, MASSA, ITALY**



KEPLER CRATER dominates the center of a bright lunar ray system. Kepler measures 19.5 miles (32 kilometers) across. Encke Crater lies 50 miles (80 km) to the southeast. (12-inch Gladio 315 Lazzarotti Optics telescope at f/25, Lumenera Infinity 2–1 CCD camera, 0.055-second exposures, best 300 of 2,000 frames, taken April 10, 2006, at 16h17m UT, from Bangkok, Thailand) /// **PAOLO LAZZAROTTI AND TIZIANO OLIVETTI, MASSA, ITALY**



SCHILLER CRATER has a stretched-out shape because the meteorite that formed it struck the Moon at a steep angle. The crater measures 106 by 44 miles (171 by 71 km). (12-inch Gladio 315 Lazzarotti Optics telescope at f/25, Lumenera Infinity 2–1 CCD camera, 0.055-second exposures, best 468 of 2,000 frames, taken April 10, 2006, at 16h28m UT, from Bangkok, Thailand) /// **PAOLO LAZZAROTTI AND TIZIANO OLIVETTI, MASSA, ITALY**



VITELLO CRATER lies at the southwest part of the Moon, along the southern edge of Mare Humorum, the "Sea of Moisture." Note the smaller crater offset from Vitello's center. (12-inch Gladio 315 Lazzarotti Optics telescope at f/25, Lumenera Infinity 2–1 CCD camera, 0.055-second exposures, best 375 of 2,000 frames, taken April 10, 2006, at 14h47m UT, from Bangkok, Thailand) /// **PAOLO LAZZAROTTI AND TIZIANO OLIVETTI, MASSA, ITALY**

NGC 1579 in Perseus sometimes is called the Northern Trifid because of its resemblance to the Trifid Nebula (M20) in Sagittarius. A bright star several times the Sun's mass illuminates NGC 1579. (20-inch RC Optical Systems Ritchey-Chrétien telescope at f/8, SBIG STL-11000 CCD camera, LRGB image with exposures of 615, 120, 54, and 108 minutes, respectively) /// **R. JAY GABANY, SAN JOSE, CALIFORNIA**

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